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PRELIMINARY DESIGN AND EVALUATION OF A UNAVCOM II FACILITY

FINAL REPORT

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Prepared by: Dave Friberg
D. Friberg

Reviewed by: _____
W. F. Payne

Released by: Dave Friberg
D. Friberg

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PROJECT TEAM

The project team for Canadian Astronautics Limited (CAL) was composed of:

Mr. D. Friberg
Mr. D. Vakili
Dr. P. Woods

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17. Abstract

A preliminary design and evaluation of a proposed unattended navigation and communication facility (UNAVCOM II) is presented. This facility is intended to offer improved low and high altitude navigation and communication aids in Canada's remote and arctic airspace. Also included in the report is a plan for the further development of the UNAVCOM concept to the production of a complete, operational prototype.

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17 Résumé

Ce rapport présente un projet et une évaluation d'une installation proposée pour la navigation et les communications (UNAVCOM II) qui opére sans surveillance. Cette installation vise á offrir dans l'espace aérien canadien des régions arctiques, et peu accessibles, des aides à la navigation à basse et haute altitude ainsi qu' aux communications. Le rapport présente également un plan pour le dévelopment ultérieur du concpt UNAVCOM, jusqu' à la production d'un prototype opérationnel complet.

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1. INTRODUCTION

1.1 Summary of Contents

This report was prepared by Canadian Astronautics Ltd (CAL) under contract to the Transportation Development Centre. It contains an evaluation and preliminary design of a second generation, prototype Unattended NAVigation and COMmunication Facility (UNAVCOM II).

Section 1, the introduction, gives a brief history of the work performed in this area prior to the start of this contract. In addition it outlines the program objectives and the design specifications of the proposed UNAVCOM II facility.

Section 2 describes in detail the preliminary design of each subsystem to be included in the proposed facility.

Section 3 summarizes the results of a reliability analysis intended both to verify the feasibility of the reliability requirements outlined in Section 1 and to identify possible problem areas.

Section 4 gives a summary of the cost of each subsystem defined in Section 2 and presents an estimate of the total 10-year life cycle costs of each station.

Section 5 presents a plan for the further development of the UNAVCOM II facility from its current preliminary design stage to the completion of one year of Arctic field trials.

Section 6 summarizes the results of this study and puts forward certain suggestions for possible alterations to the original UNAVCOM concept.

This report is intended to thoroughly familiarize the reader with the preliminary UNAVCOM II design and to provide enough information to allow a proper assessment of the feasibility of deploying such stations in Canada's north. It is the result of an extensive research and design effort not all of which can be adequately described herein. We would be pleased to accept inquiries concerning this report and its contents.

1.2 History

In a study carried out in 1975/76, under contract to the National Airspace Planning Office of Transport Canada, SaTel Communications Limited identified a requirement for improved low and high level communications and navigation aid in Canada's Arctic and remote areas. The study indicated that these improvements could be implemented by the deployment of remote facilities throughtout these areas. It was suggested that the facilities include: a non-directional beacon, a VHF air/ground communications system, a communications backhaul link and some means of providing automatic VHF bearing replies to pilots in the area on request. The remoteness of the proposed sites also dictated that the power required to run this equipment be generated on site.

In 1978, the Transportation Development Centre (TDC) of Transport Canada was tasked to undertake the development and evaluation of an Unattended Navigation and Communications (UNAVCOM) facility. During tests conducted between January 1979 and September 1981, this system performed reasonably well in most respects with the major exception being reliability. It was concluded from the project that a UNAVCOM facility is practical in remote locations but that further development of the prototype would be required.

In November 1982, Canadian Astronautics Limited (CAL) began an evaluation study and preliminary design of a second generation prototype (UNAVCOM II). The results of this work are summarized in this report.

1.3 Objectives

The overall objective of the UNAVCOM program is to improve air-ground communication and navigation aids in Canada's arctic and remote northern airspace. The immediate goal of the current contract is to prepare a preliminary design of a second generation prototype system (UNAVCOM II) and to evaluate the capability of the unit to provide reliable and cost effective navigation services. This report also contains recommendations for the development of this UNAVCOM II station from the preliminary design phase through to the delivery to Transport Canada of a fully tested operational system.

1.4 System Specifications

No communication or navigation systems currently exist in many regions in Canada, so any facility installed in these areas would be an improvement. Of course, the more elaborate the service supplied, the higher the cost. The overall system will be designed as a series of modules or sub-systems any of which can be removed independently.

A system in which all modules are present shall:

1) Provide reliable VHF air/ground voice communiations 95% of the time anywhere within a 160 km radius of the site, consistent with the line of sight limitations of the local terrain and based on an antenna height of 30 metres above ground level.

2) Provide non-directional beacon (NDB) towards which bearings can be obtained accurate to ± 5% for 95% of the readings taken anywhere within a 100 km radius of the site. In computing the NDB accuracy, allowance shall be made for deviations in excess of allowable limits due to ground conductivity anomalies and shall be based upon the use of a 30 metre antenna.

3) Provide automatic bearing and range replies via the VHF air/ground voice communications system. This information will be obtained using a Secondary Surveillence Radar equipped with a voice synthesizer.

4) Provide both voice and data communications between the site and a central manned control station. This backhaul system will be linked both to the VHF A/G system and to a Telemetry and Command System in the UNAVCOM station.

5) Operate from a stand-alone power source with no connection to the regular electric power grid.

6) Operate in the field under Arctic conditions for a period of one year without routine maintenance and with a probability of 0.9, or greater, that there will be no total failure of either the navigation or communications subsystems during the year.

7) Provide an operating availability of 99.9% throughout the year for both NDB bearings and the VHF bearing replies.

2.0 DESIGN DESCRIPTIONS

2.1 Summary

To meet all the system specifications outlined in Section 1.3, the following seven subsystems must be incorporated into the UNAVCOM II station:

1) EQUIPMENT ENCLOSURE
2) NON-DIRECTIONAL BEACON
3) VHF AIR/GROUND COMMUNICATIONS
4) COMMUNICATIONS BACKHAUL
5) TELEMETRY AND COMMAND
6) TALK-BACK SECONDARY SURVEILLANCE RADAR (TSSR)
7) POWER SOURCE

Reliability studies described in Section 3.0 indicate that each of these subsystems requires a mean time between failure in excess of 20,000 hrs. This figure is extremely difficult to achieve during the prototype development stage of any product, and it cannot be verified without extensive field use. For this reason commercially available units will be purchased wherever possible. To date suppliers have been located for the following subsystems:

ITEM	DESCRIPTION/MODEL NO.	MANUFACTURER
Equipment Enclosure	14' DND approved aluminum trailor	Champion Truck Bodies
NDB	ND 500	NAUTEL
NDB TOWER	POLESTAR PA-90-B	POLESTAR
VHF A-G COMMUNICATIONS	JOHNSON 2-way radio Model 242-406	JOHNSTON
COMMUNICATIONS BACK HAUL	Radio telephone with automatic channel evaluation (RACE)	MARCONI

Table 2.1 Manufacturer's List for Proposed UNAVCOM II Equipment

Each of these selections was made on the basis of a performance evaluation of all existing commercial units. The details of these evaluations can be found in Sections 2.2, 2.3, 2.4 and 2.5 of this report.

No commercial source for the TSSR or the Telemetry and Command Systems has been located. The development of the T&C system will be included as part of the follow-on UNAVCOM work described in Section 3 and CAL is currently investigating the feasibility of the separate development of a suitable TSSR. Preliminary design descriptions of both these systems are included in Sections 2.6 and 2.7.

The ORMAT, Closed Cycle Vapour Turbine is the best, currently available remote power system. The final decision has been delayed pending the outcome of on-going develoment work on several other power sources. Figure 2.1 shows a typical UNAVCOM station. Notice that a North Wind Power, HR2 wind turbine has been included. The reasons for this along with an outline of the rational behind selecting the ORMAT CCVT are included in Section 2.8.

2.2 Equipment Enclosure

The equipment enclosure proposed for the UNAVCOM II station is a DND approved nominal 4 meter aluminum container, similar to that used by CAL on the SARSAT program. This enclosure will be required to provide adequate protection for the electronics from the harsh Arctic weather conditions expected at a typical UNAVCOM site. However, only a small portion of the enclosed area will be used to house electronics. The remaining area will provide emergency shelter for repair and maintenance personnel.

There are disadvantages associated with using such a large enclosure. These include:

- Higher capital purchase price.
- Increased shipping costs.
- Increased difficulty in installations.

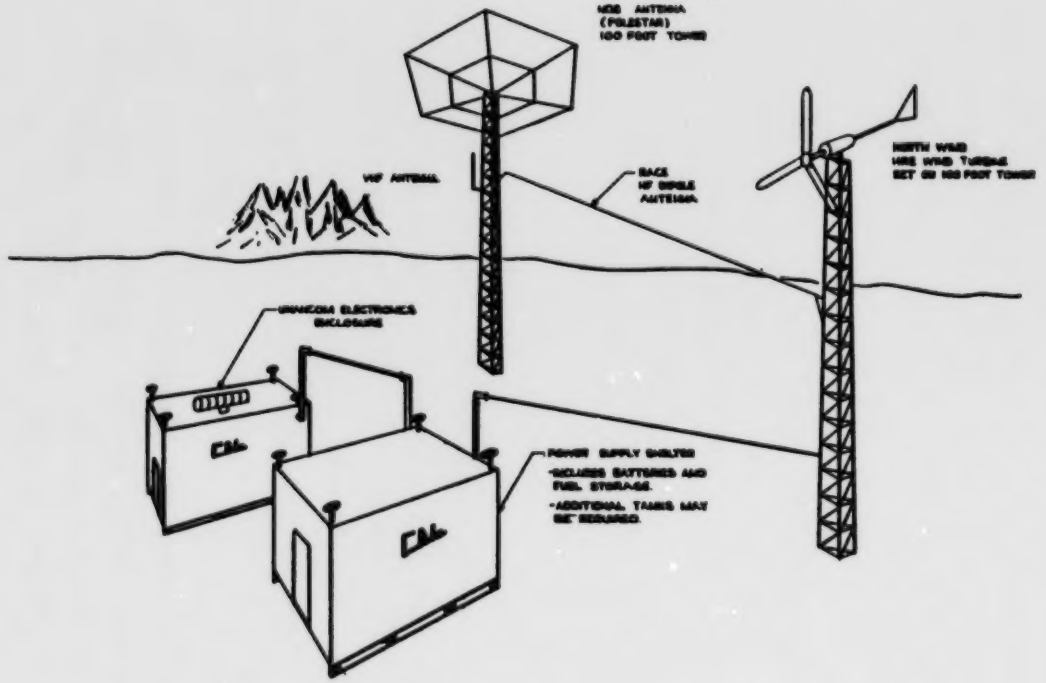


FIGURE 2.1

POSSIBLE LAYOUT FOR A UNAVCOM STATION, EQUIPPED WITH WIND TURBINE AND PARTIAL TEG BACK-UP.

Despite these problems, the risks involved in servicing remote sites demand that allowances be made for the possibility of being stranded on site by bad weather conditions.

Given that this emergency shelter is mandatory, incorporating it into the equipment enclosure offers one major advantage. It will be possible to use this area as a heat sink for the electronics by using thermostatically controlled fans to circulate air from the electronics room into the emergency shelter area during periods of high ambient temperature. The electronics room will be heavily insulated to ensure that with these fans off, an adequate temperature is maintained in the electronics room during cold periods. Manually operated space heaters can be used to heat the emergency shelter area when occupied. A proposed layout for this enclosure is shown in Figure 2.2.

2.3 Non Directional Beacon

The NDB subsystem contains the following elements:

1) The Transmitter and Control Unit
2) The Antenna Tuning Unit (ATU)
3) The Antenna

In viewing the UNAVCOM I experience, no fault could be found with either the Transmitter and Control Unit or the Antenna. An ice related jambing problem was encountered with the ATU. The NDB proposed for use on UNAVCOM II station will therefore be largely the same as that used on the UNAVCOM 1 station. There are some differences however and these are discussed in Sections 2.3.1 through 2.3.3.

One difficulty encountered in integrating the UNAVCOM I NDB into that station was the fact that NAUTEL employs a positive grounding system. Unfortunately this problem appears unavoidable as NAUTEL has continued to use this grounding arrangement on their newer models.

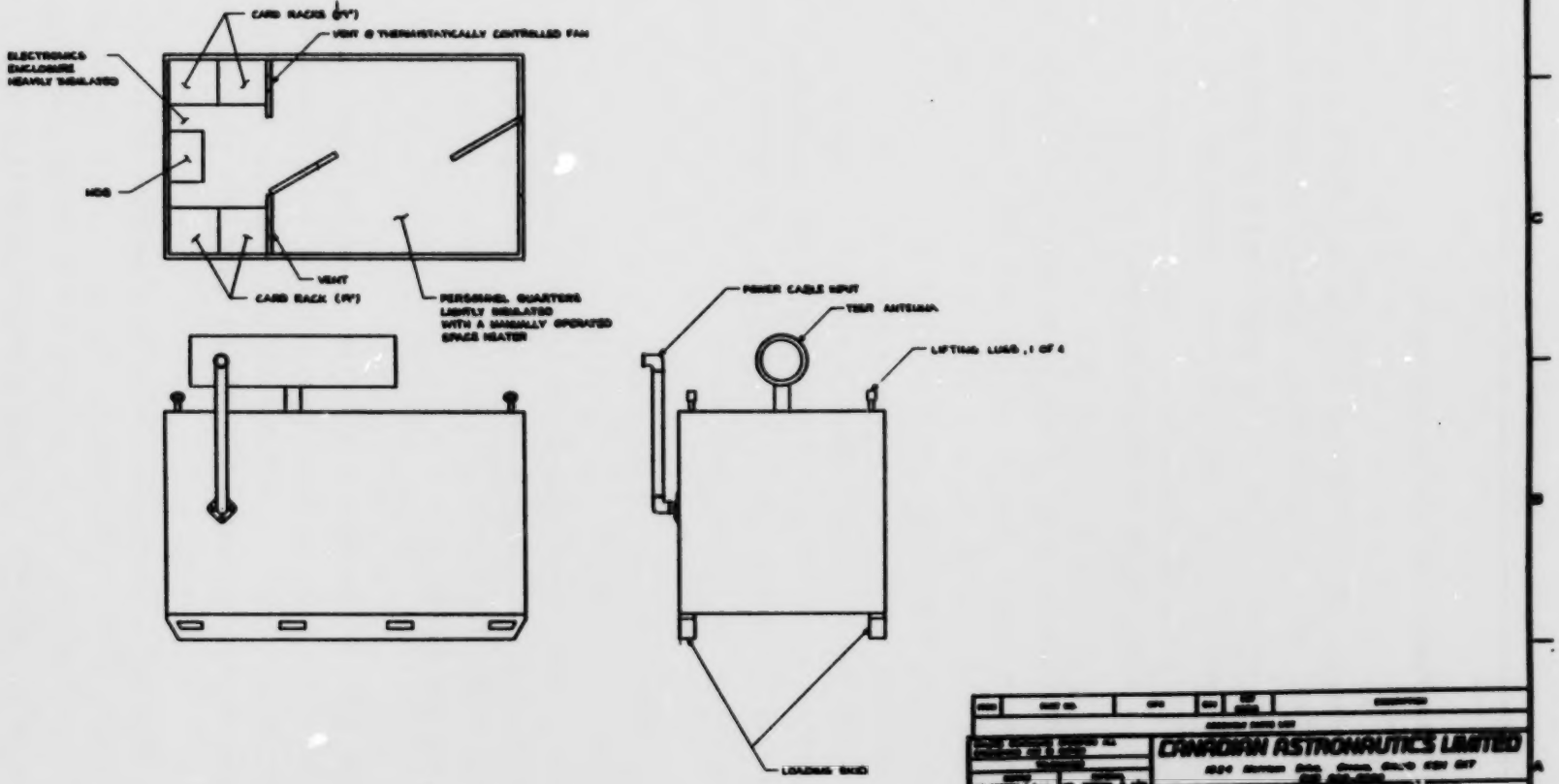


FIGURE 2.2

UNAVCOM II ELECTRONICS ENCLOSURE

2.3.1 NDB Transmitter and Control Unit

The Transmitter and Control Unit used on the UNAVCOM 1 station was the NAUTEL NEL7703. This unit performed flawlessly and would be used on the UNAVCOM II station except that NAUTEL is now producing an upgraded unit, the ND500, which is a smaller, more efficient unit intended for remote applications. Normally, CAL would resist changing a well proven design but there are several good reasons to opt for the newer unit:

1) The NEL7703 has four, 25 watt power amplifiers each of which must be operational to provide the 100 watt output required. The ND500 uses two, 50-125 watt variable output amplifiers, either of which can provide full power. This unit is therefore fully redundant and is supplied with a means of automatically switching to its backup in the event of a failure. No means is normally supplied to override this selection, but if possible CAL will modify the ND500 to allow the Telemetry and Command system to determine the main/standby status.

2) The ND500 consumes 310 watts of ac power to produce a 100 watt output. The NEL7703 uses at least 400 watts under the same conditions. These figures are quoted in ac power consumption since grid power will be used in the prototype station. Equivelant figures for dc power consumption are similar, but vary with the voltage used.

3) The ND500 is packaged in a lockable, weather proof seam welded box with a fully gasketed door. Its operating temperature range is -40°C to +55°C, 0 - 95 % humidity while the NEL7703 is specified to operate over -10°C to +55°C, 0 - 95 % humidity.

These advantages alone would easily be outweighed by any lack of reliability in the ND500. Since the unit is new it is not yet possible to determine this reliability, but if the same design and manufacturing standards are maintained, the reliability should actually improve due to a less complicated design.

2.3.2 Antenna Tuning Unit (ATU)

The automatic antenna tuning unit is used to match the NDB transmitter to the antenna in order to compensate for changes in the antenna characteristics due to weather conditions. In the UNAVCOM I system, this matching was done using mechanically driven variable inductances. During the UNAVCOM I field trials a frost build-up caused the power thread on the mechanical drive to jam.

This ATU will not be used in the UNAVCOM II station. The ND500 is equipped with an upgraded ATU in which the mechanical drive mechanism is hermetically sealed and permanently oiled. This model NX 400 TUB would appear to be an improvement over the older version; however, any moving part is subject to failure and hence the reliability remains questionable.

CAL has proposed the development of a non-mechanical tuning unit for use in the UNAVCOM II station. This system would replace the servo mechanism used to alter the loading coils with a microprocessor controlled feedback loop which would switch different sized loading coils into the antenna circuit.

This design would offer the following advantages:

1) The unit would contain no moving parts, with the exception of hermetically sealed switching relays. It is possible to replace these with switching diodes but this could increase the chances of sustaining damage by lightning strikes.

2) The unit would consume less power because of the elimination of the servo motor and driver amplifier.

3) The expected cost of the unit, excluding profit and non-recurring engineering is estimated at $2800 in quantities of 30 as compared to $3500 for NAUTEL's tuner.

4) The non-mechanical tuner would be considerably smaller and lighter.

In order to tune the antenna the digital ATU must set the inductance of the switched impedances to match the antenna capacitance which varies from 250 to 1250 pF. This is done by monitoring the voltage and current outputs from the transmitter and switching inductances to set the phase angle between them to zero. Since the capacitance of the antenna is dependent on weather conditions, the phase angle must be continuously monitored and adjusted.

It is also necessary to match the output resistance of the transmitter (50 Ω) to the antenna resistance (2 to 30 Ω) in order to minimize reflected power. These resistances do not normally vary but will differ between antenna installations. The digital ATU will contain provisions to measure and adjust forward and reflected power at the the time of installation. If desired these values can be continuously monitored via the Telemetry and Command system in order to evaluate the performance of the NDB. The adjustment of the antenna radiation resistance will be done manually using a variable tap transformer.

The level of sophistication of the digital ATU will be determined in future discussions with Transport Canada. A trade-off exists between simplicity and low cost versus ease of operation. Appendix A of this report contains a preliminary design description of the ATU along with cost estimates and a description of various options possible.

2.3.3 NDB Antenna

The umbrella top loaded tower used in the UNAVCOM I station was a good selection largely because of its low cost. If a similar antenna were to be used in the UNAVCOM II station, the following design modifications would be recommended. (See Figure 2.3 for dimension definitions.) However, despite the low cost, CAL does not recommend this antenna for the UNAVCOM II station.

A better, though more expensive alternative would be a flat-top antenna such as the Polestar PA 90B. This design reduces the antenna reactance without degrading the radiation resistance. The total cost of this antenna, including a custom ordered top winding optimized for the frequency of operation, is $14,500. It is recommended that this tower be used in the UNAVCOM II station for two additional reasons:

1) The aluminium tower construction will allow it to be erected on site using a hand operated winch. This is particularly important for sites where heavy equipment is not available.

2) The reactance of this antenna type does not vary as widely with environmental conditions. Only 10% of the total reactive compensation requires adjustment by the ATU. The NDB would therefore be less sensitive to ATU malfunctions.

A servo-mechanical ATU designed for use in connection with this antenna is available from Polestar for $3,000.

Polestar also manufactures a 40 meter antenna, the PA 120B. This antenna offers a 17% increase in efficiency and is only marginally more expensive. It will therefore be considered for UNAVCOM stations where conditions would allow for the erection of this higher antenna.

2.4 VHF Air/Ground Communications

The Johnston two-way radios used in the UNAVCOM I station performed without failure during its one year test period. However, the performance of the radio system was degraded by the relatively low position of the antenna. It is recommended that the same Johnson AM two-way radio (Model 242-406) be used in the UNAVCOM II station. The antenna however will be a standard ground plane antenna mounted on top of the NDB tower. NAUTEL uses this configuration and CAL is currently awaiting the delivery of a NAUTEL report on the suggested means of implementing this change to the NDB tower. The exact location of the NDB antenna will depend on local conditions.

The VHF A/G system also includes switching circuits to automatically set the transmit/receive status and to switch the redundant transceiver in. This equipment is still available from the UNAVCOM I station but will not be utilized in the UNAVCOM II station. The standard of workmanship and general quality of this equipment does not meet CAL standards.

2.5 Communications Backhaul System

Appendix B contains a report prepared by Hicom Design Limited under sub-contract to CAL, which presents a detailed evaluation of several possible methods of backhauling voice and data communications from remote UNAVCOM stations to a central control facility. The system recommended for inclusion in the prototype station is the MARCONI Radio Telephone with Automatic Channel Evaluation (RACE).

It seems very possible that the MSAT or MOBILE COMMUNICATIONS satellites currently being developed by DOC will be ready in time to be used in the actual UNAVCOM network. If it is ready, this system may preseant a number of advantages over the RACE system and will perhaps be the recommended system. However it is too early to fully evaluate this system, and it is not yet available. Using the RACE system during the prototype trials will provide a means of backhauling data for the purposes of this experiment and will also present the opportunity to fully evaluate the performance of the RACE system which at this point is also uncertain.

The RACE system is a relatively new device, but uses standard HF technology. It has no proven reliability performance record and many people familiar with the use of conventional HF systems in the Arctic are reluctant to employ a similar system in the UNAVCOM network. Despite the problems normally encountered with HF communications systems, the relatively low cost of the RACE system makes it an attractive solution.

The main disadvantages of standard HF Telephone systems are:

- The inherent variability of the ionosphere
- The need for skilled operators
- The necessity of identifying a frequency providing adequate transmission for a given call
- The difficulty of effective intercommunication to an automatic telephone system.

Typical HF propagation paths depend greatly on the frequency, transmitted power, receiver sensitivity, modulation techniques, ionospheric storms, sun spot activities etc. However, in most cases there is at least one frequency in the HF band that is useable. The problem is finding that frequency.

The RACE system does this by continually broadcasting short bursts of data from a central station over frequencies from 2 to 30 MHz. Each remote station monitors the signal strength and quality of each burst and stores the frequency which displays the best transmission characteristics. When called upon to communicate to the central station the remote station broadcasts over this frequency.

Typical transmission paths vary from a few kilometres to several thousand kilometres depending on the number of hops. For the UNAVCOM II system the longest distance to a manned ACC would typically be less than 500 km. The major question is whether or not the RACE availability at this range is good enough to make it suitable for use in the UNAVCOM II network. The system has been installed and used in Western Canada, Eastern Canada and Baffin Island, but no performance data has as yet been completed. The following performance has been determined using computer simulations:

65 km path	99.9% availablity
965 km path	98.3% "
270 km path	98.7% "
490 km path	99.2% "

These figures are not unreasonable except that the duration of a typical loss of communications is even less predictable than the overall availablity. Outages as long as six hours have been experienced and there is no reason why even longer periods might not occur.

It is difficult at this time to guarantee that the RACE system will perform satisfactorily in this application, but only the RACE system and the standard 4-6 GHz SCPC earth terminals will be available for use in the prototype station. The 4-6 GHz system is well proven and with the exception of the incorporation of certain power reduction techniques, no further development or testing is required. The use of DAMA schemes could significantly lower the cost of the 4-6 GHz system when used in the full UNAVCOM network but for the purposes of the UNAVCOM II test, the cost would likely exceed $100,000. At $30,000 for a complete system the RACE is cheaper both for this test and the full network. This test program therefore offers an ideal opportunity to evaluate the RACE system since it presents an opportunity for both immediate and long term cost reduction.

2.6 Telemetry and Command

The Telemetry and Command system will have three main functions in the UNAVCOM II station.

1) To monitor station operational status and provide alarm signals and performance measurements to a manned central station via the communications backhaul link.

2) Provide the ability to manually control a number of simple ON/OFF functions both from the station and remotely from the manned central station. The idea being to allow an operator to override on-site equipment designed to determine the main/standby status of each subsystem.

3) Perform general station housekeeping tasks.

Any communication system and in particular the RACE system proposed for use in the UNAVCOM II station will be subject to interference. To avoid the possibility of incorrect commands being issued, extensive error checking and perhaps error correction will be performed on T&C data stream. The computer and transmission time available to perform those checks will determine exactly how they are implemented.

The complete system will consist of two units:

1) A microprocessor based control unit located at the UNAVCOM station capable of autonomous operation but coupled via a modem to the central station.

2) A microprocessor controlled central control unit located at a manned site capable of communicating with and controlling any number of UNAVCOM stations.

It will not be possible to complete the design of either of these units until the designs of all other station subsystems have been finalized. However, Hicom Design Ltd. is currently developing a similar T&C system intended for use in VOR systems. The design presented here is a variation on this system, which has been modified to better suit the UNAVCOM II station. It is not clear whether it would be cost effective to attempt to use this particular T&C system, but any system used will be similar.

The microprocessor used in the VOR site (as well as the manned centre) is the Rockwell AIM 65/40. This is a commercial low-cost single board computer. It is complete with a one-line, 40-character display, a keyboard and a 120 line/minute column thermal printer. CAL would not necessarily recommend that this microprocessor be used. If the system were developed at CAL, a Military standard single board microprocessor such as the SBC 80/30 would be chosen instead. Shown in Figure 2.4 is a simplified

block diagram of the proposed UNAVCOM T&C system. The particular blocks in this system are described below.

a) Microcomputer

The microcomputer continuously monitors the status and health of the remote site. It steps through a series of measurements such as frequency, voltage, status and other inputs as required by the UNAVCOM II station. After a series of measurements has been completed, they are stored in memory. If a fault is detected, this data is sent automatically back to the manned centre. The microprocessor then continues with the next set of measurements with no interruption.

b) Digital Voltmeter (DVM)

The DVM is capable of measuring dc voltages in the 0-2 V range with a $3\frac{1}{2}$ digit resolution. All system voltages will be scaled and connected into the DVM to provide BCD measurements of these voltages to the microprocessor. One of the prime functions of this DVM will be to monitor the NDB output using a LF receiver coupled to the DVM.

c) Status INPUT/CONTROL OUTPUT

The status input circuits provide an interface between the microprocessor and a number of switch and/or relay contact inputs. These switches may be located anywhere in the vicinity of the UNAVCOM station. The logic status of these contacts indicate the presence or absence of specific alarm conditions. The system as shown will accept 16 such inputs but this is easily expandable to whatever number is required.

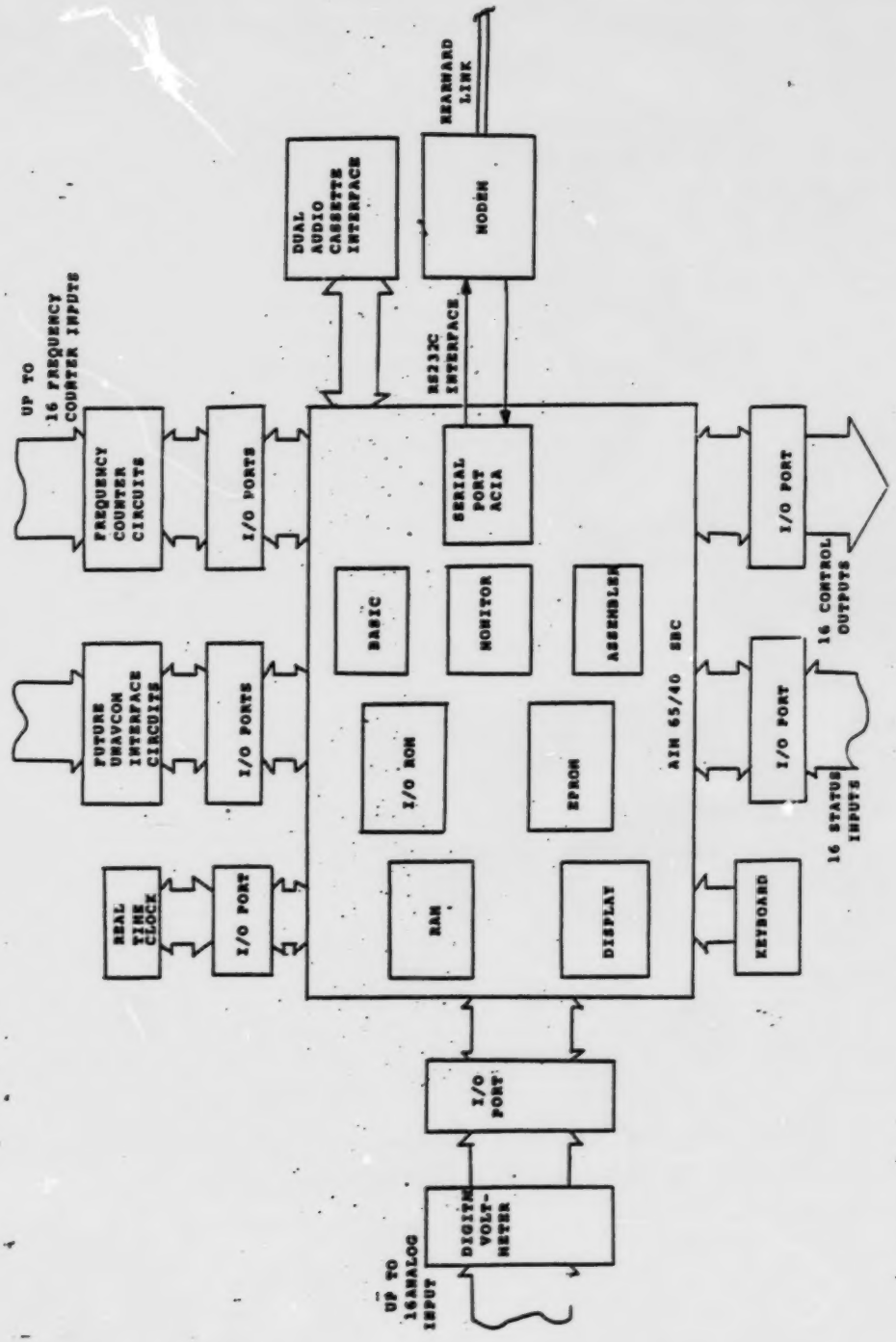


Figure 2.3.

T&C SYSTEM BLOCK DIAGRAM

Similarly, the microcomputer can control outputs that drive solid state relays to turn equipment on and off as required.

d) Real Time Clock (RTC)

The real time clock is a peripheral IC which provides the microcomputer with two functions:

i) Continuously updated time and date.

ii) Accurately timed single or continuous interrupts.

The clock, once started, provides continuously updated BCD inputs of month, day, date, hours, minutes and seconds to the microprocessor. This information is then used to identify status information recorded by the microprocessor. The RTC has its own back-up battery so that time information will not be lost in the event of a system power failure.

The timed interrupt will be used to arm an external timer, which must be periodically disarmed by the microprocessor. If the microprocessor does not successfully disarm this circuit, control could be passed to a redundant microprocessor or an alarm issued to the main control station.

e) Frequency Counter

The six digit frequency counter is capable of counting analogue or digital input signals in the .1 Hz to 99999.9 Hz range with an accuracy of a few PPM. Up to 16 separate signals can be measured. The use of frequency dividers will therefore allow all RF frequencies used in the UNAVCOM station to be remotely monitored.

f) Parallel Input/Output Port

Provisions will also be made to expand the T&C system to include additonal 1/0 capabilities. One possible use for these ports would be to allow the T&C system to externally monitor the status of other micro-processor controlled equipment in the site. For example this will allow the T&C system to read the output of a shaft encoder incorporated into the TSSR should this prove necessary.

It may be necessary to add and delete various functions, based primarily on inputs from system operators during the field trials. The use of readily reprogrammable processors facilitates this feature.

Problems were encountered in the UNAVCOM I station which appear to be the result of lightning strikes. To avoid similar problems in the UNAVCOM II station a great deal of care must be taken to protect the electronics from current and voltage surges generated by direct strikes as well as from the RF interference generated by storms in the area.

2.7 Talkback Secondary Surveillance Radar (TSSR)

The UNAVCOM I station employed a Radio Direction Finder to provide automatic VHF bearing replies to pilots in the vicinity of the station. This system did not function well, particularly at long range, where bearing replies tended to be inaccurate, with errors occasionally as high as 180°.

The possibility of replacing the RDF with a TSSR was looked at as a means of remedying this problem. This evaluation showed that the adaptation of a simple SSR to operate as a talk-back unit in the UNAVCOM II station is both feasible and highly recommended.

The primary reason behind this claim is the inherent advantages in the SSR system:

1) The TSSR can calculate both bearing and range, an RDF cannot. Both the TSSR and RDF systems can generate incorrect bearing replies to low altitude aircraft at long range, but if the aircraft's altitude and range are known, the pilot will be able to assess the probable accuracy of the bearing reply from an SSR.

2) Aircraft identification codes will be automatically supplied to the UNAVCOM station, allowing flight paths to be recorded.

3) Assuming an aircraft is equipped with an LF radio direction finder, the information provided by a ground based RDF is redundant to that provided by the NDB except in areas of magnetic compass uncertainty. Furthermore, the NDB is more reliable and more accurate.

The only major drawback of the TSSR system is that a transponder will be required on board any aircraft wishing to use this facility.

Canadian Astronautics is currently investigating the feasibility of developing a simplified TSSR suitable for use in the UNAVCOM II system. It is possible that CAL will have such a system available in time to incorporate it into the UNAVCOM II station.

2.8 Power Source

2.8.1 General

This section outlines the procedure followed in selecting a power supply subsystem to be incorporated into the UNAVCOM system. There are many means available to produce the 750-900 W required by a UNAVCOM station, but not all these systems are capable of meeting the overall specifications of the UNAVCOM station, so rather than perform a detailed evaluation of all possible generating systems these specifications were used as a means of screening out unsuitable systems.

The UNAVCOM station will be required to operate under arctic conditions for a minimum of one year between scheduled maintenance or refuelling visits. Its overall reliability over a one year period must exceed 90%. In addition, it must provide an operating availability of 99.9%.

As discussed in Section 3, in order to achieve this overall objective it will be necessary for the MTBF of the power supply to be over 20,000 hours assuming a completely redundant backup is included in the design. All indications are that this will be the most difficult design specification for the power supply to meet.

The following factors were also included in the evaluation of the power source:

1) Life cycle costs including capital investments, maintenance, repair and fuel costs.

2) Fuel type with respect to safety, reliability and transportability.

3) Maintenance requirements with particular attention to technical expertise required.

The systems given serious consideration for this application were:

GENERATOR TYPE	MANUFACTURER
Closed Cycle Vapour Turbine	ORMAT SYSTEMS INC.
Cycle Charged Diesel	MECHRON ENERGY LTD.
Fuel Cell	Englehardt Industries/ Energy Research Corporation
Radio Isotope Generator	Atomic Energy of Canada Limited
Stirling Cycle	Sun Power Corp./ HOMACH Ltd.
Spark Ignition/Kerosene	Foster and Miller and ASC.
Thermal Electric Generator	GLOBAL THERMAL ELECTRIC LTD.

Table 2-2 List of Potential Power Sources

Consideration was also given to the use of wind power or photovoltaics as a means of reducing overall fuel consumption.

Based on these considerations, the ORMAT CCVT is recommended as the best currently available prime power source. Wind and solar power availability at particular site location will determine their suitability for use in a UNAVCOM system, but both appear able to be of use somewhere in the overall network. The reasoning behind these statements is outlined in detail in the following sections.

2.8.2 Fuel Cells

Two manufacturers, Englehardt Industries and Energy Research Corporation, claim to be able to supply fuel cell power systems able to meet the UNAVCOM requirements. Unfortunately neither manufacturer is currently producing such a system nor has either previously built a system of this type. As expected, no accurate cost estimate could be obtained.

Fuel cells have been used in aerospace applications (e.g. Skylab, Space Shuttle) with impressive results. These systems however were fueled by hydrogen and oxygen in their pure states. Neither of these gases is suitable for use at remote, arctic sites.

The systems proposed by Energy Research Corporation and Englehardt Industries employ methanol/air and ammonia/air respectively. Despite maximum theoretical efficiencies near 65%, the reformers used to convert the methanol and ammonia and other peripheral devices drop this efficiency into the neighbourhood of 20-25%. For the methanol system, the fuel consumption required to produce a 1 kW output would be 2.5 lbm./hr. So despite a very impressive efficiency, the fuel costs, which are largely composed of transportation charges, are merely average for a remote system. This problem is further aggravated by the uncertain availability of both these fuels.

Thus, the fuel costs, along with the lack of a reliability performance record, effectively eliminate the fuel cell from use on the UNAVCOM project. However, neither of these problems is technically insolvable, so it would be wise to continue monitoring research and development progress on these devices.

2.8.3 Closed Cycle Vapour Turbine

The CCVT is an organic fluid Rankine cycle turbine. It can be powered by either propane or diesel fuel, and is normally delivered to the site as a completely integrated system suitable for Arctic use. ORMAT has delivered nearly 4,000 of these units world-wide and can point to third party studies which record mean time between failures in excess of 23,000 hrs. Experience on the Trans Alaska pipeline shows the probability of a total failure of a redundant ORMAT system to be less than 0.0001% using propane as a fuel.

The major drawback of the CCVT is its high specific fuel consumption, which is estimated at 2.14 kg/kW-hr. The initial capital cost is also high at $138,000 (U.S., FOB Israel).

The fuel consumption estimate given above represents an overall efficiency of 5%. The primary reason for this poor efficiency appears to be the low boiler operating temperature (130°C). CAL does not have access to detailed information on the thermodynamic properties of the ORMAT working fluid, but the maximum possible Carnot efficiency of this process is calculated at 15%. If this ratio of Carnot efficiency to actual efficiency can be maintained at higher boiler temperatures, raising the maximum cycle temperature to 400°C would produce an efficiency of 17%.

ORMAT has recently indicated its intention of doing exactly this. By incorporating a series of minor changes to the system design aimed at overcoming problems associated with the resulting increase in turbine working stress and the high temperature breakdown of the working fluid, ORMAT hopes to have obtained an overall efficiency of 12% by late 1984. Unfortunately this upgraded CCVT will not be ready in time to be used in the UNAVCOM II prototype.

As an interim solution CAL recommends the use of a wind turbine or photovoltaic array to reduce the demand for prime power, thus lowering the average fuel consumption. ORMAT has already completed the development of such a hybrid system in conjunction with North Wind Power Company. The feasibility of incorporating this system into a UNAVCOM station is discussed in Section 2.8.9. It should be mentioned here however that in order to operate in a hybrid system the ORMAT CCVT must use propane as a fuel. This allows the burner output to drop to pilot flame level when the wind turbine is operating. A liquid fuel burner can only be cut back to 25% of its peak output if it is to be re-started reliably. Furthermore, propane normally contains far fewer impurities and burns much cleaner than diesel fuel, thus reducing the frequency of required cleanings.

2.8.4 Cycle Charge Diesel (CCD)

The CCD system, designed and built by Mechron Energy Systems, employs a four-cylinder diesel generator to intermittently charge a large capacity battery bank. The batteries are charged and discharged on a 24 hour cycle, with a charge duration of 2 to 3 hours. The batteries are sized so that they are discharged to 75-80% of the full capacity. This allows the generator to recharge at a rate which the diesel engine operates near its best efficiency point.

This system was designed to overcome 2 main problems which plague conventional diesel generators operating at low power outputs:

1) A 1 kW continuous load represents a small fraction of the rated output of the smallest multi-cylinder diesel. Attempting to run a diesel under these conditions will result in very poor thermal efficiency and high engine vibration levels.

2) Operating the diesel on a 10% duty cycle reduces the number of operating hours per year from 8700 to 870. In more familiar terms this is equivelant to dropping the mileage on a diesel truck operating at 60 mph from 500,000 miles to 50,000 miles per year.

The major drawback with the CCD system is the questionable reliability associated with automatically starting and stopping a diesel engine. Mechron performed accelerated life cycle tests on 2 self-starting diesel engines prior to developing the CCD system. The engines were started, run for 15 minutes and then stopped on a 2 hour cycle. Failures occurred at 500 and 1100 cycles, which on a 24 hour cycle would be equivalent to 12,000 and 26,400 hrs respectively. As an overall system MTBF these figures are not adequate and if one includes the probability of all other types of failure (i.e. battery, generator, etc.) plus the fact that these figures were compiled under laboratory test conditions and on relatively new engines, it is clear that the CCD system does not meet the UNAVCOM II reliability speacifications.

Five CCD systems have been delivered for testing to Newfoundland Telegraph and Telephone, and as expected each system experienced 2 or 3 failures during the first year of operation. However, none of these failures resulted in a total loss of system power, primarily due to the fact that the battery bank allows 3 days of normal operation in which to repair a failure. These emergency repairs along with the scheduled maintenance puts the expected number of visits to 7 or more per site per year.

The overall efficiency of the CCD system is somewhat dependant on the operating environment, but on a yearly basis figures of 12% have been achieved by NTT. This translates to a fuel consumption of 1.75 lbm/hr, at 1000 kW. This is the best measured specific fuel consumption of any suitable 1 kW power supply currently on the market.

In addition to this high efficiency the CCD offers a number of other advantages including:

1) it does not employ any exotic technology and can be maintained and serviced by a diesel mechanic.

2) it is easily adaptable for use in a hybrid system employing wind or solar power to reduce fuel consumption.

3) it is designed and built in Canada.

4) the CCD is delivered as a completely operational unit, including a shelter which has a temperature regulated area designed for the installation of user supplied equipment. The general quality and workmanship are excellent and the total price is approximately $150,000 CAN F.O.B. OTTAWA.

Unfortunately, the CCD system does not meet the UNAVCOM II reliability and maintenance requirements as they currently are written. Section 6 of this report puts forward suggestions concerning changes to these specifications. Hopefully these would lower the life cycle costs of the system without seriously impairing the overall performance. The desire to use the CCD system was the major factor behind these suggestions. Power cost savings of up to 50% over the ORMAT system can be obtained if the power source were allowed to deviate from the specified requirements.

2.8.5 Thermal Electric Generator (TEG)

The TEG is a remarkably simple and therefore reliable device. It makes use of the Seebeck principle to generate power by creating a temperature difference across a junction of dissimilar metals. One manufacturer of these units is Global Thermal Electric.

The hot side is heated to 550° C using a propane fired burner, the cool side is heat sunk to the ambient air temperature. The efficiency of the system is defined by the temperature across the junction and is therefore a function of ambient temperature.

Globals TEG's are not equipped with a dynamic feedback control on the burner output. For this reason, the burner output must be set high enough to ensure adequate power during the least optimum operating conditions. The following calculation demonstrates the effect of this fact on overall system efficiency.

The Global 5120-48, their largest single unit, is a 48 V, TEG rated at 108 W at 24° C. The fuel consumption under these conditions is .24 kg/hr. If this efficiency could be maintained at the required 1 kW output, the fuel consumption would be 2.22 kg/hr.

However, this is not the case. The TEG's must supply full power at the highest anticipated temperature with some margin of safety. For every 1° C temperature rise there is a .29% decrease in power output. To operate at 40° C rather than 24° C requires a 5% increase in burner output. Considering a 10% margin of safety to be an absolute minimum, puts the required fuel consumption at:

$$2.22 \text{ kg/hr} \times 1.05 \times 1.10 = 2.57 \text{ kg/hr}.$$

The fuel consumption is raised even further if redundancy is needed to meet the reliability requirements. 10 units are needed to provide 1000 Watts, if 12 units are used in parallel to provide extra reliability there is a further 20% increase in fuel consumption:

$$S_{FC} = 2.57 \times 1.2$$
$$= 3.08 \text{ kg/kW-hr}$$

or $$S_{FC} = 6.78 \text{ lbm/kW-hr}$$

The specific fuel consumption is increased even further if the load which it is operating is not constant, since the TEG burner must supply maximum power even when the load is reduced. This effect however can be minimized by adding batteries to the system.

A system employing 12 TEG's would cost approximately $128,000 (CAN.) (F.O.B. Alberta). The required enclosure would be extra.

2.8.6 Radio Isotope Thermal Electric Generator (RTG)

Atomic Energy of Canada Ltd. has been considering the development of a radio isotope generator for a number of years. The fuel of choice would be Cesium 90 with a TEG used to convert the heat generated by the isotope to dc power.

The system could operate for five years between refuelling and since it would contain no moving parts its reliability would be excellent. The major obstacle to the development of this system is its high development costs. AECL officials have estimated the cost of the first system at $1,000,000 with subsequent systems costing $400,000 to $500,000. These costs are simply too high when compared with life cycle costs of other power supply types.

Interestingly, the cost of the radio isotope generator is directly proportional to the power output. A scaled down version of the UNAVCOM might be practical using a radio isotope generator.

The cost of the isotope represents roughly 15% of the price of an RTG. The remainder is primarily due to packaging, handling, government safety inspections, etc. There is no reason to expect an appreciable reduction in any of these costs.

2.8.7 Sterling Cycle

There are two companies, Homach (U.K.) and Sun Power Corporation (U.S.A.), which are currently developing 1 kW Sterling cycle generators. Both have completed the development of first generation prototypes and are hoping to begin production by 1984.

The Homach unit, which appears to be nearest production, is currently available in a 120 W version. This unit does not use the conventional sliding piston design. Instead, the armature of a linear alternator is mounted on a flexible diaphram covering the top of the gas chamber. The gas chamber itself is divided into hot and cold regions by a spring mounted light weight displacer. The entire system is designed to resonate at 100 Hz whenever heat is applied to the high temperature chamber. This heat can be supplied using any source capable of producing a high enough temperature.

The efficiency of the 120 W unit is roughly 11-12%. The unit has not undergone enough tests to determine its reliability but early indications are promising. For example a 60 Watt unit installed to power a hazard light on an island off Scotland operated flawlessly for 2 years before running out of propane.

The Sun Power Corporation generator also uses linear alternator but is based on the standard sliding piston design. This design approach results in a better surface area to displacement ratio and hence the efficiencies are higher. Laboratory tests have achieved 35% but overall efficiencies of 24% are targeted for the production version.

A closed metal cylinder (1), containing helium (4), is heated at the bottom by a propane burner and cooled at the top by cooling coils (2) connected to a radiator.

Occupying most of the interior of the cylinder is a lightweight displacer (3), spring-mounted so that it is free to vibrate vertically without touching the cylinder walls.

Small amplitude vibrations of the displacer are sufficient to move most of the helium up and down between the heated and cooled zones of the cylinder, causing the pressure of the gas to rise and fall alternately.

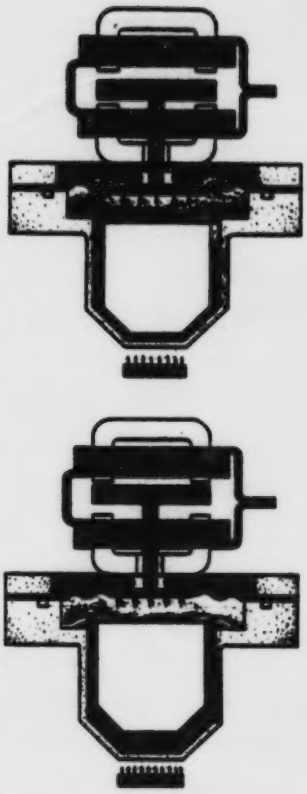
A flexible metal diaphragm (5) which seals the top of the cylinder is deflected in and out by changes in the pressure of the gas.

These deflections of the diaphragm cause a permanent magnet (6) to move between the coils of an alternator (7), thus producing an AC electrical output.

Because the magnet is spring-mounted to the engine body (8), its vibrations are transmitted to the displacer.

The strengths of the springs and the masses of the moving parts are accurately balanced to ensure that the whole system vibrates at a resonant frequency of about 100 Hz.

The illustrations on the right show the positions of the moving components at the two extremes of their movements. In the upper illustration the working gas is cooled, and in the lower it is heated.



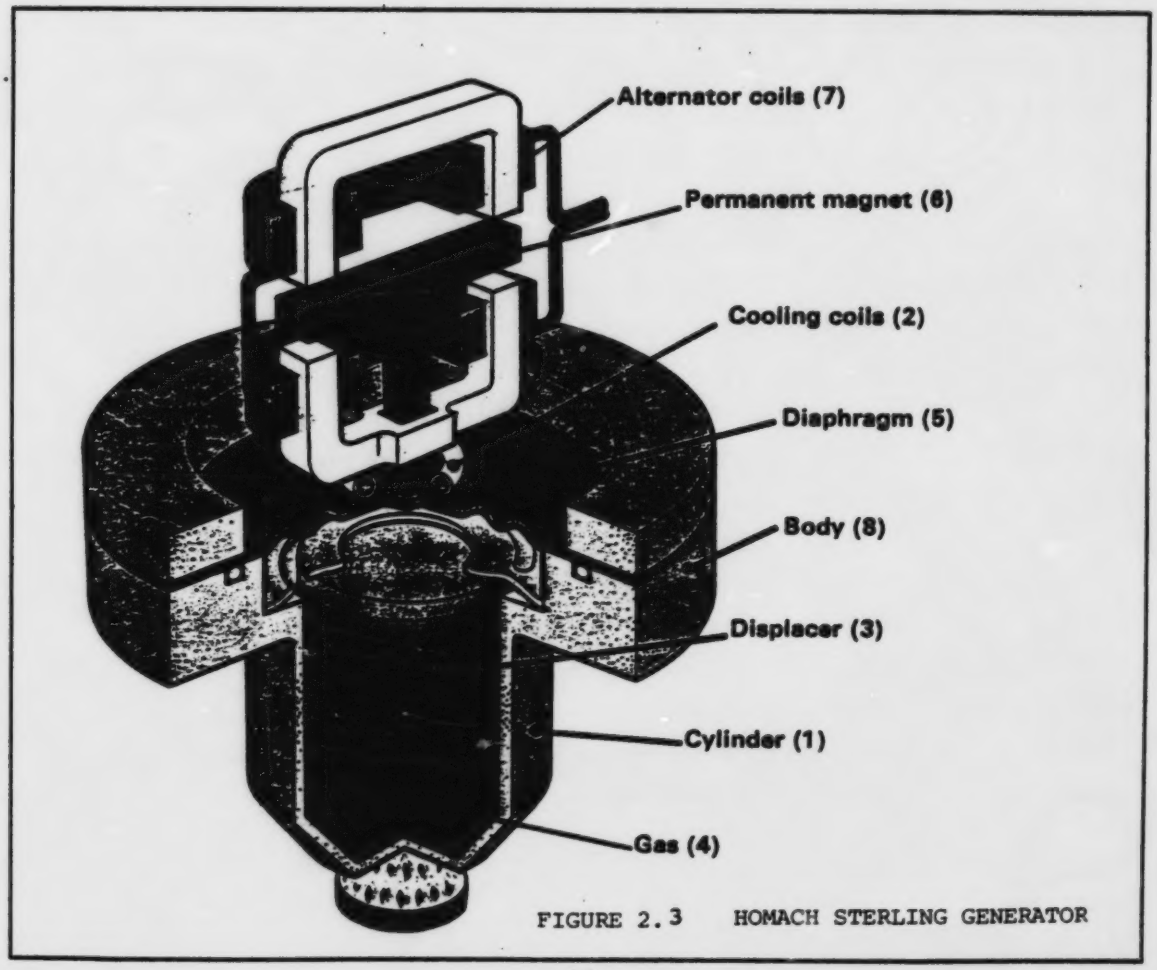


FIGURE 2.3 HOMACH STERLING GENERATOR

The sliding fit between the piston and the cylinder wall is subject to wear so the reliability of this design might not be as good as the HOMACH design. Sun Power is not overly concerned about this since they are directing their efforts towards markets where an MTBF of 10,000 hrs is acceptable. There appears to be no reason however why this figure could not easily be increased.

The efficiency of these systems plus the fact that they can be run on virtually any fuel make them extremely attractive for use in the UNAVCOM system. Unfortunately, neither system will be available until late 1984.

2.8.8 Soft Energy Sources as Fuel Economizers

The term soft energy is used here to describe a power system which uses a naturally occurring energy source available at the site. Wind and solar energy are the only such sources which are universally available across Canada's north. Photovoltaic systems and wind generators which have extremely high reliability are currently available but are not recommended as prime power sources due to the uncertain availability of both wind and sunlight.

To maintain a continuous output of power some highly reliable source of prime power must be incorporated into the system in order to recharge the storage batteries during long periods of low wind or heavy cloud cover. This prime power source could be operated continuously, so the inclusion of a soft energy source into the power source can only be justified if the overall cost of power produced is reduced. For this to be achieved, the cost of energy produced by the soft energy source must be less than the fuel costs of the prime power source.

The cost of producing power from a soft energy source depends on the cost and performance characteristics of the conversion system and on the availability of the resource itself. To determine which, if either, of the wind or solar systems should be incorporated into the system, the cost of fuel delivered to the site, the average sunshine and the average windspeed at the site in question must be known.

The following sections describe the procedure which should be followed in assessing the feasibility of either wind or photovoltaics as a means of generating remote power.

2.8.9 Wind Energy Assessment

The instantaneous power available in the wind varies approximately as a function of the wind velocity cubed. If the exact wind speed versus time history for a given area is know it is possible to determine the total energy available over any time interval. It is also possible to determine the storage capacity required to prevent a total loss of power during periods of low wind speed.

Unfortunately not all of this energy can be converted to useful power for four main reasons.

1. The maximum theoretical efficiency of a wind turbine is about 59%. In actual fact the overall generation and storage efficiency rarely exceeds 35%.

2. All wind turbines have a maximum output and must use some means of lowering their efficiency, when wind speeds would normally be high enough to cause this limit to be exceeded.

3. All wind turbines have a maximum wind speed above which they are forced to shut off completely to prevent structural damage and a minimum wind speed below which they are unable to produce any power.

4. During long periods of high wind speeds, the batteries can become full charged. If the average load continues to be lower than the power available, this excess energy is wasted.

For a given system it is still possible to make reasonable estimates of the power produced in a particular period if the wind velocities are known. These estimates become much more difficult and less accurate if it is necessary to treat the wind speed as a random variable.

The standard procedure for modeling wind availability is to assume a Raleigh distribution of wind velocity duration. A normalized wind velocity duration can be produced, and used as a means of estimating the power output spectrum based on the average wind, and system performance characteristics.

This type of calculation has been performed by the North Winds Power Company in evaluating the HR2, Variable Axis Rotor Control System (VARCS) wind turbine. The results are shown in Figure 2.5 which gives the average energy output versus the mean wind speed. Notice that no useable power is produced at mean wind speeds below 13 km/hr and that the maximum monthly output approaches a maximum level of 1000 kw-hr at an average wind speed around 35 km/hr. Average wind speeds above this point results in more frequent high wind shut downs and hence less power.

When operating in a hybrid configuration, the wind system must also be evaluated in terms of the total percentage of the required load power which it produces. This percentage will be a function of the ratio of average power to load requirement and of the systems energy storage capacity. Measurements performed on a hybrid system, using an ORMAT turbine as the prime power source produced the graph shown in Figure 2.6.

This graph along with the graph in Figure 2.6 were used to calculate the storage requirement for 90% or better power generation at various average wind speeds from 13 km/hr to 35 km/hr. this information was then used to calculate the average cost per unit energy produced by the wind using the following cost estimates.

BATTERY STORAGE (LEAD-ACID)	17¢/W-hr
HR2	$18,000
TOWER	$15,000
EXTRA INSTALLATION CHARGES	$15,000

The results are shown in Figure 2.7.

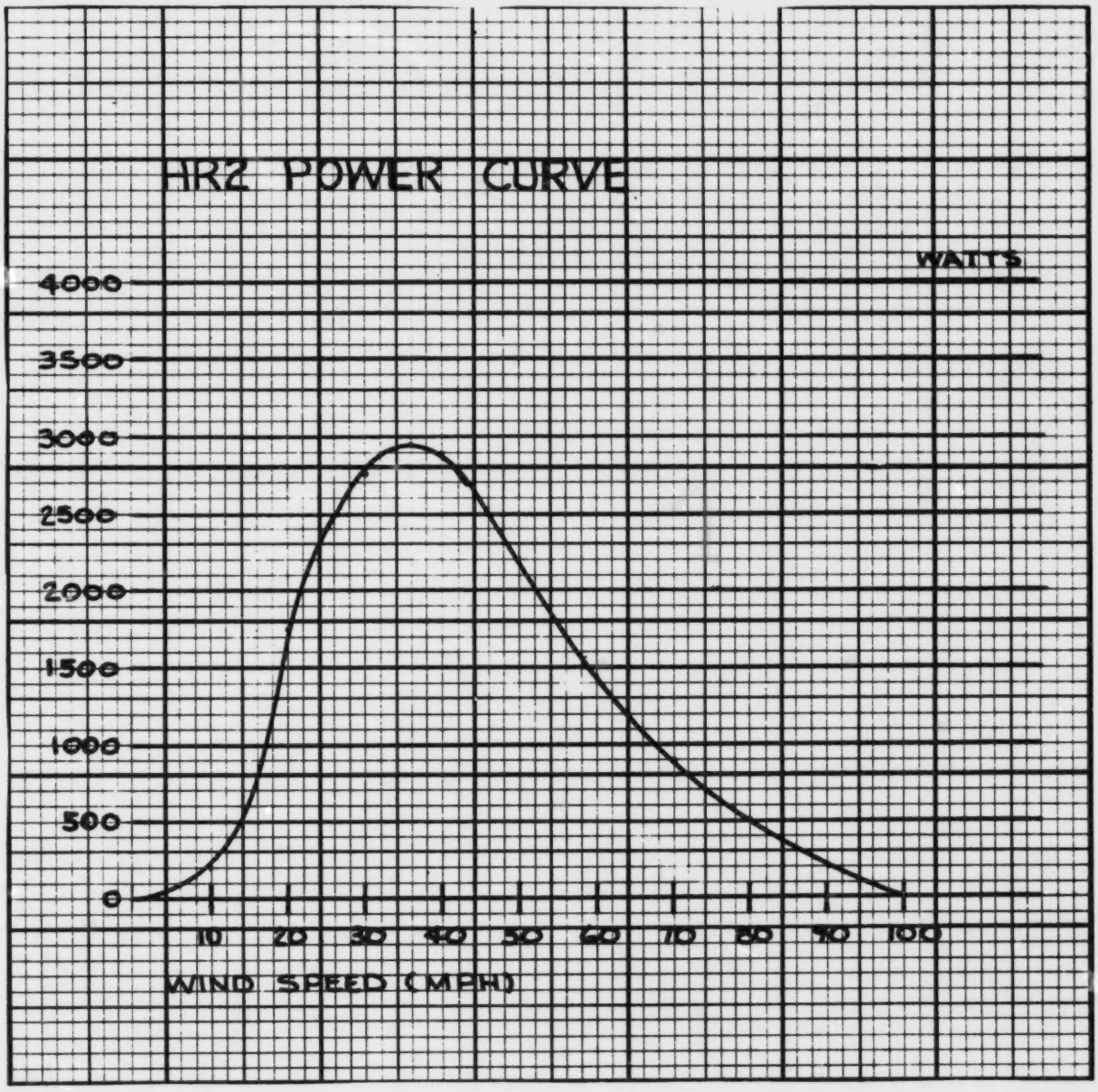


Figure 2.4

Power Curve

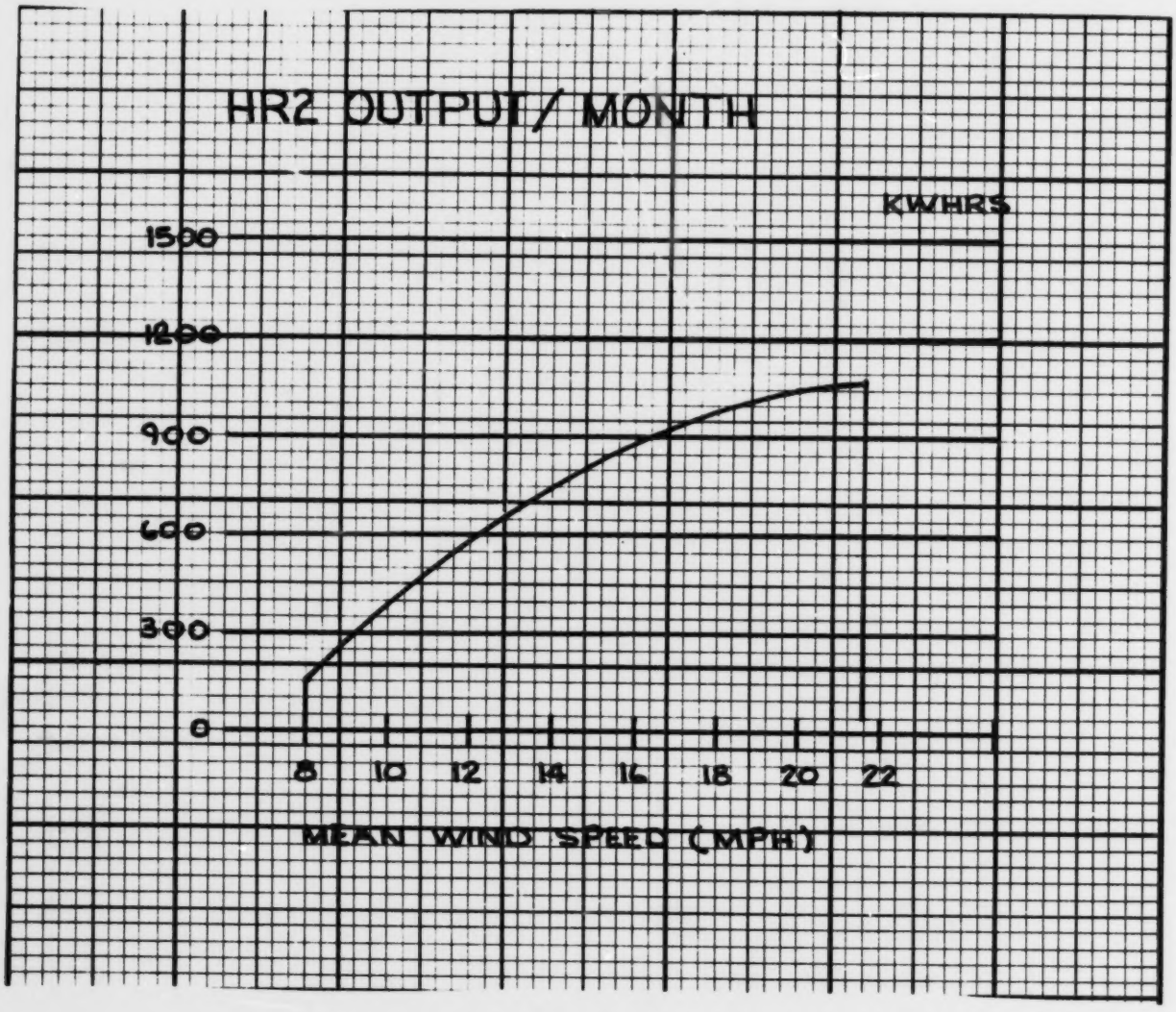


Figure 2.5

HR2 Monthly Output

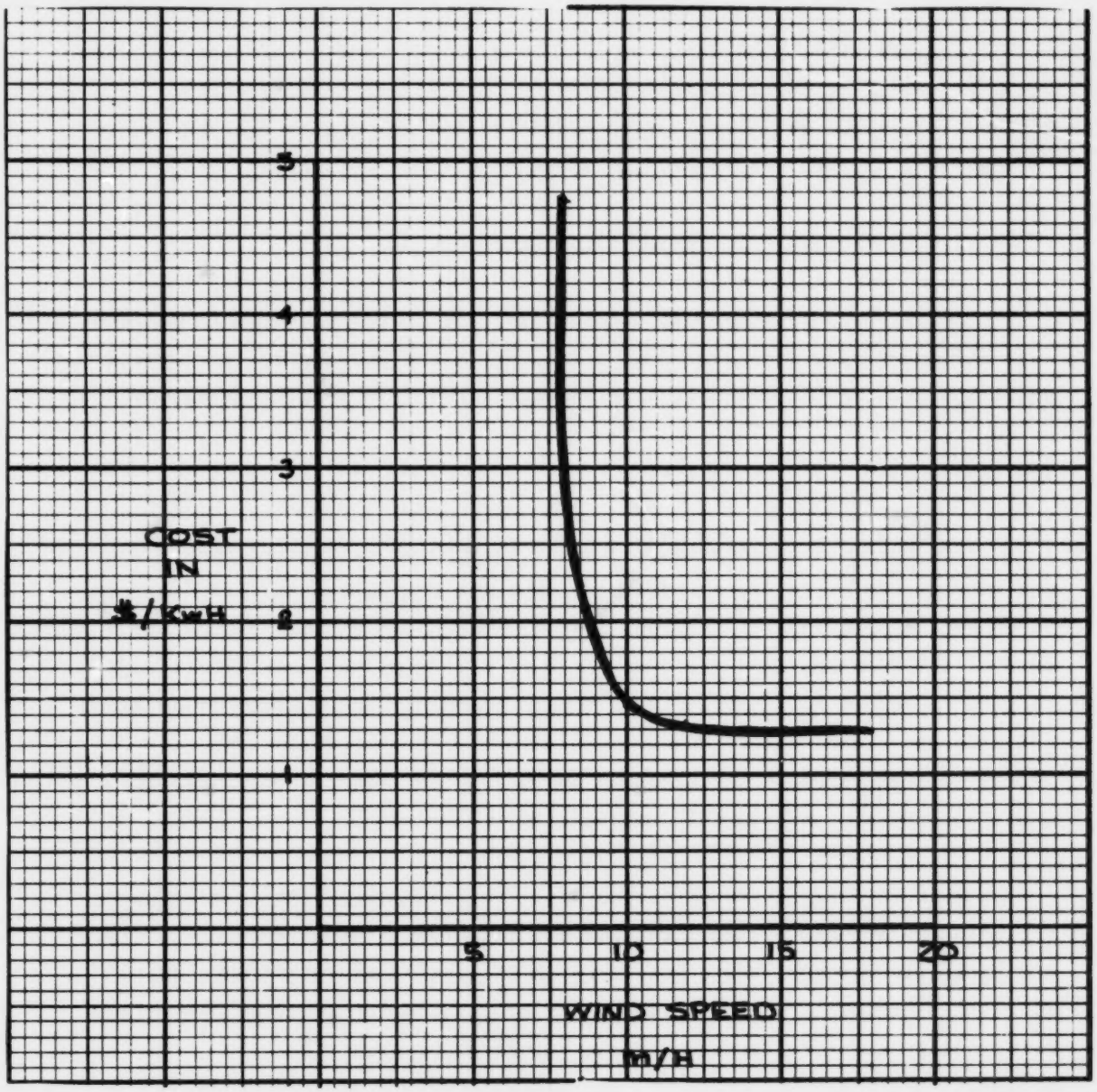


Figure 2.6

Cost of Wind Power vs Wind Velocity

No cost estimates have been produced for wind speeds below 13 km/hr. The output at this wind speed is too low and unreliable to warrant consideration.

Average wind speed data for the Yukon and Northwest Territories, then were obtained from Environment Canada. Of 58 weather stations in the Northwest Territories, 34 had average yearly wind velocities over 13 km/hr. In the Yukon only Whitehorse had an adequate average wind speed.

2.8.10 Photovoltaic System Assessment

The lowest cost per watt of photovoltaic power generated is achieved when all the PV power generated is utilized. If the average daily energy available and the maximum daily are known the required array size can easily be determined. It is also possible to calculate the total percentage of the load demand supplied by the array.

Increasing the array output beyond this point will increase the cost per watt of the PV generated power and decrease the percentage of total power generated by the prime power source, Depending on the cost per peak watt of the PV panels and the cost per watt of the prime power generated, this could result in a net saving. Thus a trade-off would have to be made for each individual case. However, an adequate general evaluation of PV performance at various latitudes can be made by considering only systems whose peak output matches the load exactly.

Most PV designs are performed using recorded data. This data however includes the effects of local weather conditions and the effects of latitude are partially masked. The comparisons in this section will be made using calculated estimates of the maximum possible insolation available assuming continuously clear conditions. These values along with a detailed explanation of the method used to calculate them were obtained from "Principles of Solar Engineering" by F. Kreith and J. Krieder.

To size the array for 100% utilization of its output, the peak array output should be set to equal the load. Figure 2.9 shows a graph of array size, calculated in this manner versus latitude. Notice that the required size increases by a factor of 1.22 between 24°N and 64°N.

The array performance must now be estimated in terms of the percent of energy used produced by the PV arrays. To do this the maximum average daily output is calculated and compared to the daily requirment. The results are shown in Figure 2.10. Notice that this fraction of total power varies from 90°% at 24°N to 68% at 64°N.

So far only the comparative sizes of arrays at different latitudes have been calculated. To determine the actual size of the array both the efficiency of the array and the local weather conditions must be known. If an efficiency of 10% is assumed the information in Table 2.3 can be used to determine the array size required. This table gives the total direct diffuse and reflected radiation actually striking an inclined surface at various latitudes at 110°W longitude.

The array size required at 65°N can be calculated by setting its peak output to 750W. The peak insolation is estimated at 20.15 $MJ/M^2/day$. A 750W load requires 64.80 MJ/day. Therefore at 10% efficiency the total insolation required on the array is 648 MJ/day, so an array size of 32 M^2 is required. Its performance in terms of percentage of power produced will be roughly as calculated previously. Figure 2.10 can now be used to estimate the array size required at any latitude where similar weather conditions exist.

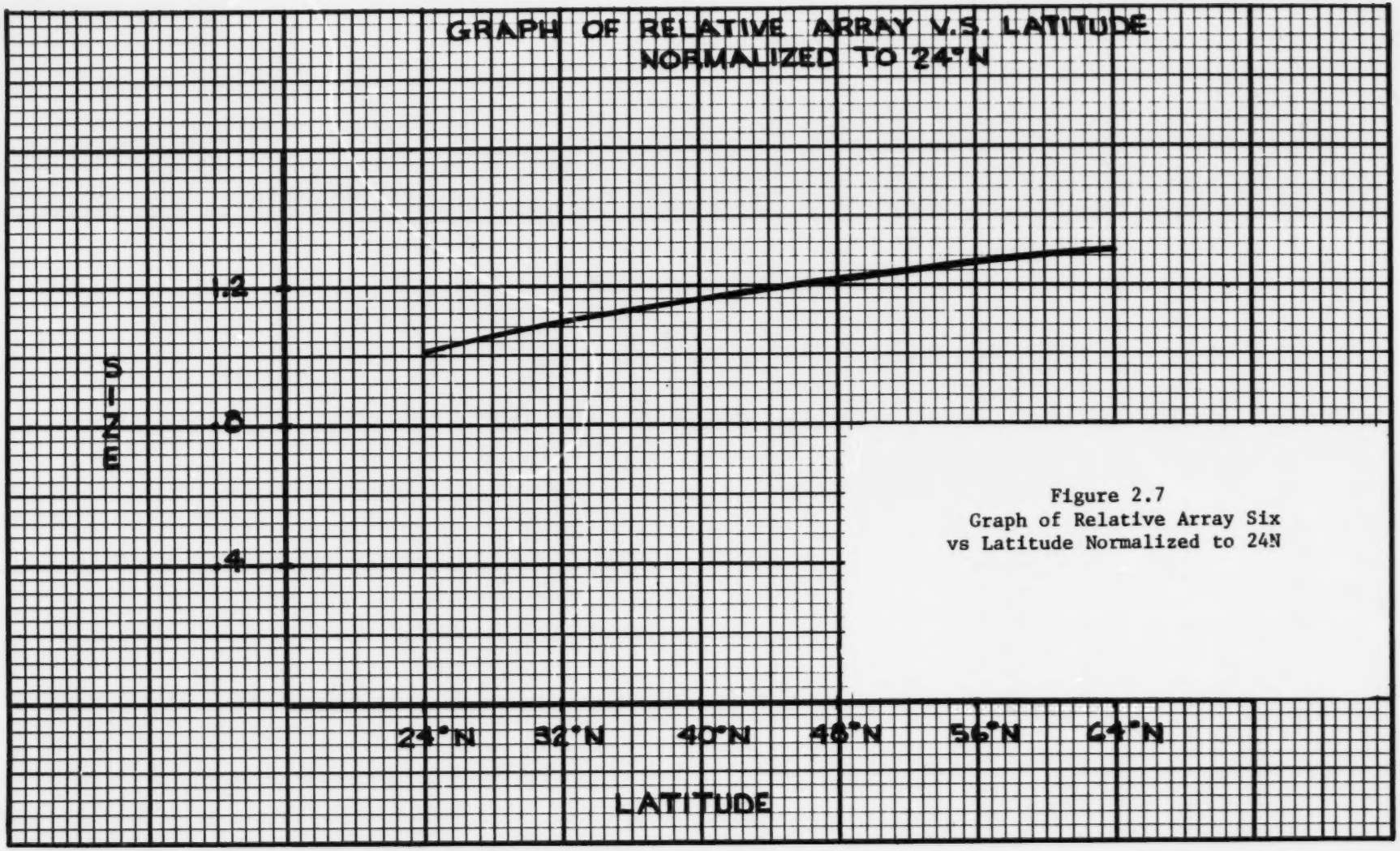


Figure 2.7
Graph of Relative Array Six
vs Latitude Normalized to 24N

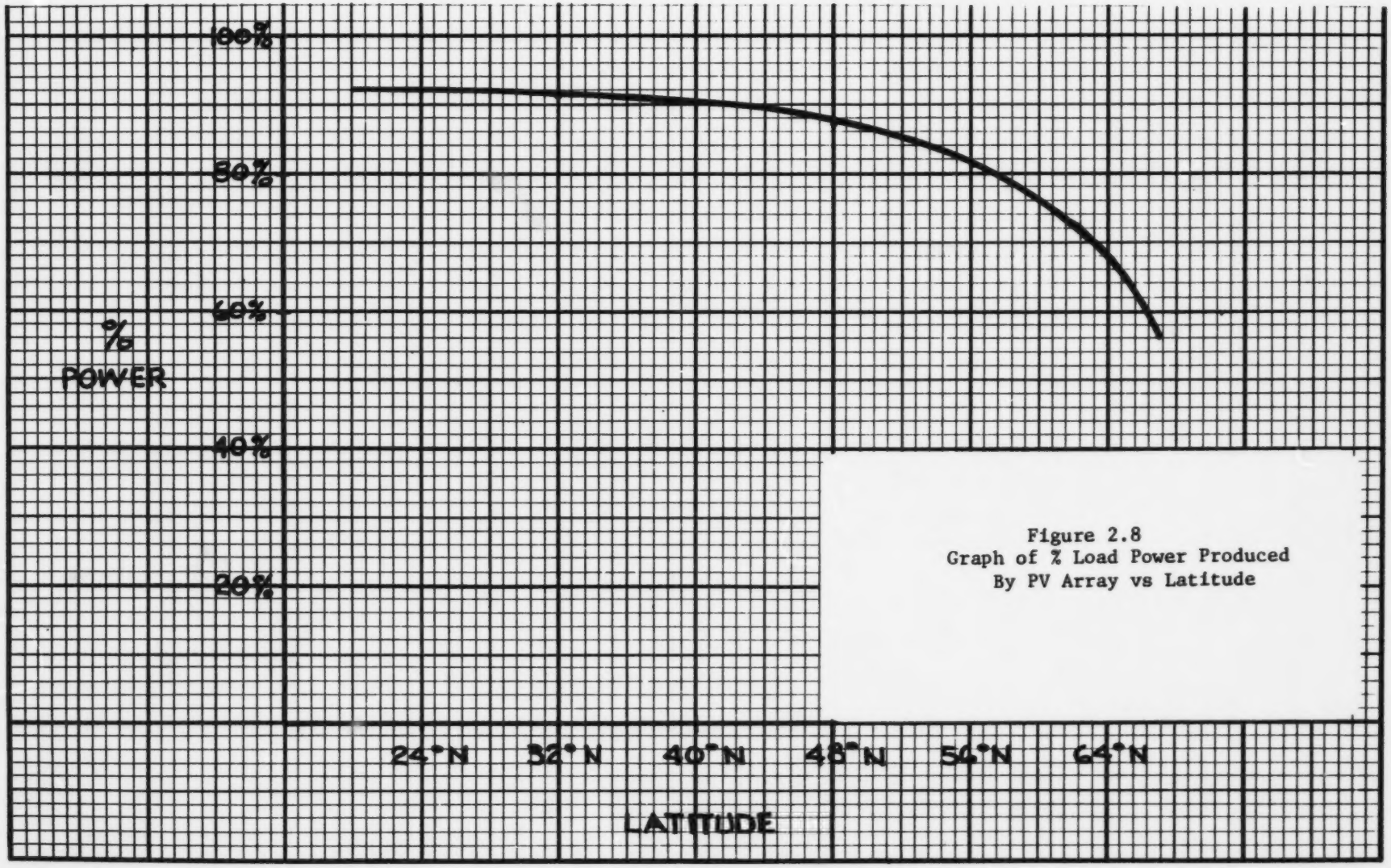


Figure 2.8
Graph of % Load Power Produced
By PV Array vs Latitude

Table 2.3 Approx. Global Insolation at 110°W Longitude and Various Latitudes

MJ/m^2/day at latitude & inclination					
MONTH	50°N	55°N	60°N	65°N	%
January	9.77	8.52	7.02	5.11	45
February	17.49	16.40	15.09	13.40	60
March	19.91	19.54	19.12	18.46	60
April	16.05	16.11	16.23	16.15	50
May	16.41	16.80	17.32	17.63	50
June	16.38	16.94	17.66	18.20	50
July	18.14	18.76	19.56	20.15	55
August	17.08	17.35	17.72	17.87	52½
September	13.35	13.13	12.93	12.56	45
October	12.40	11.75	11.02	10.13	45
November	10.39	9.30	8.04	6.49	45
December	10.69	9.13	7.14	4.06	50
Inclination	~70°	~75°	~80°	~85°	

NOTES:

1) % is percent of extraterrestrial radiation getting through to the ground.

2) Same percentages used for all latitudes - data are representative of 55°N latitude.

3) MJ/m^2/day data are direct + diffuse + reflected radiation at the inclination shown.

4) Data are monthly averages for an average year, provided by Dr. E. Norman, TPK Solar Ltd., Ottawa.

In an auxiliary power system the storage capacity does not have to be large enough to prevent total discharges of the system. However an interruption in PV generated power caused by atmospheric conditions, will reduce the overall percentage of total demand generated by the PV system. Therefore, as the storage capacity is increased, the effectiveness of the PV panels improves. The values shown in Figures 2.9 and 2.10 are maximum values, and to attain these levels a very large and therefore expensive storage capacity would be required. No means has yet been devised to perform this trade-off between battery size and system performance primarily because the duration and frequency of atmospheric interference is not known.

The problem however, tends to solve itself if lead-acid batteries are used. To optimize the reliability, life and life cycle cost of a battery it is recommended by most manufacturers that shallow discharge cycles, less than 20% if possible, be used. If the depth of discharge during a night under clear conditions is limited to 10 to 20% of the total capacity, the total capacity will consequently be between 5 and 10 days, which is usually more than adequate to optimize performance.

The recommended storage capacity for a 750 Watt system is therefore between 90 kW/hrs and 180 kW/hrs. A similar system with a capacity of 144 kW/hours was purchased in 1981 for $24,000.

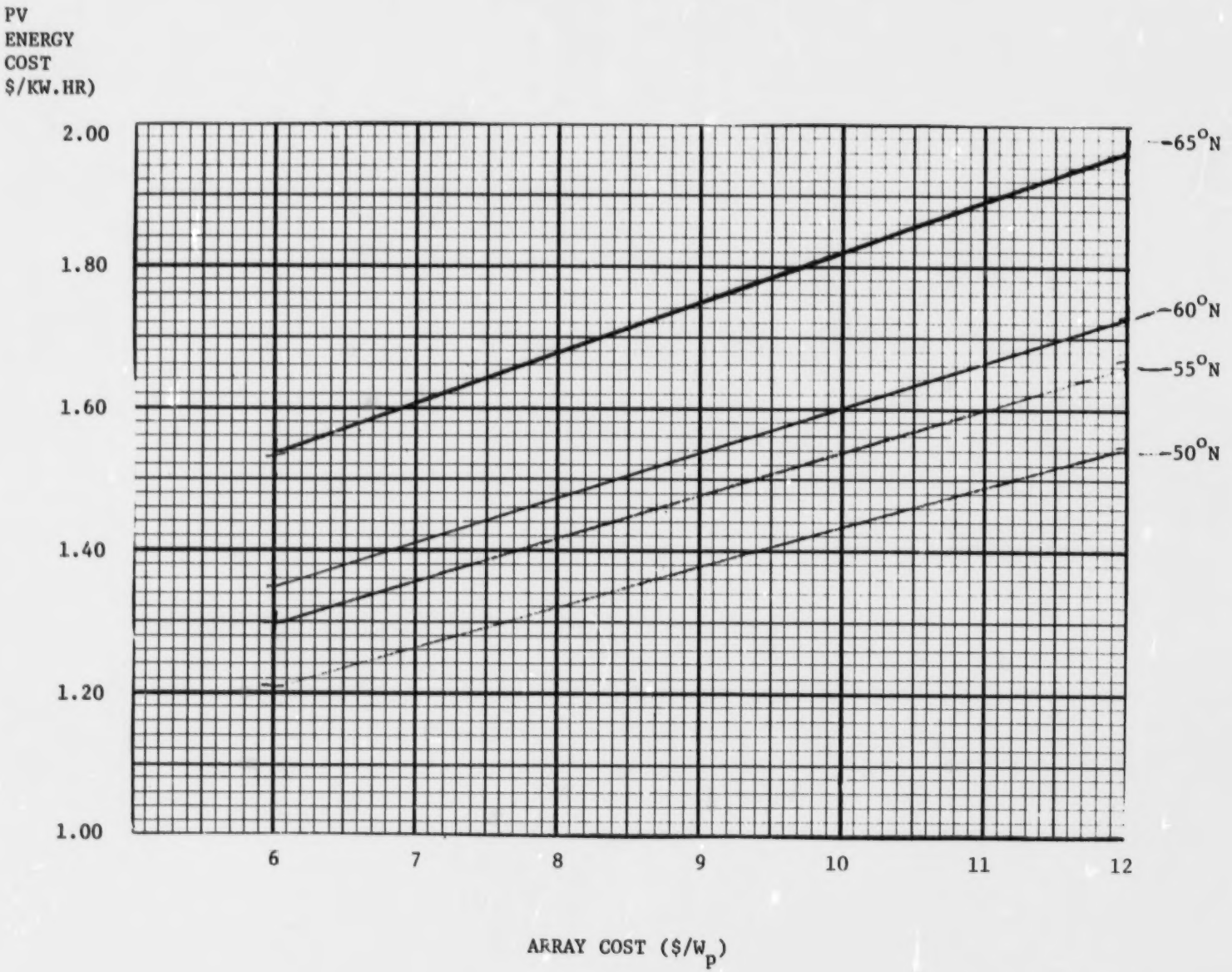
Figures 2.11 show graphs of cost per watt/hr versus PV panel costs expressed in cost per peak Watt at various latitudes. The cost per watt includes panel costs, $24,000 for a storage system and $25,000 for the array structure, battery enclosure and installation and is based on a 10 year life.

By calculating the cost per watt for fuel consumed by the prime power source, a maximum PV panel price for cost effectiveness can be determined for each latitude.

Obviously, not all sites will be suitable for the use of photovoltaics. Excessive cloud cover would exclude their use, but there are also other less devious problems. PU use in the Arctic has not been common so problems such as icing up of the collector surface have not been thoroughly addressed. Conditions at each site will have to be investigated before implementing a PV system.

FIGURE 2.9

ENERGY COSTS V.S. PV COSTS
AT VARIOUS LATITUDES



2.8.11 Power Source Recommendations and Conclusions

From the previous evaluation of current power supply technology it is clear that the 750 watts required to operate the UNAVCOM station can be generated reliably in remote locations. Unfortunately, the requirement of extremely high reliability has restricted the selection of suitable power supplies to a choice between the Thermo-electric Generator and the Closed Cycle Vapour Turbine. These devices both appear to meet the UNAVCOM reliability requirements but unfortunately, they are very inefficient. The CCVT has a slightly higher efficiency than the TEG (~5%) and is also able to operate on liquid fuels. For these reasons, the CCVT has been selected as the best currently available power supply for use in the UNAVCOM II stations.

The CCVT however is far from being an ideal solution to the UNAVCOM problem. At a 5% efficiency the CCVT can be expected to consume $30,000 to $50,000 per year in fuel, assuming, of course, that some means of transporting this much fuel can be found. As discussed in sections 2.8.9 and 2.8.10 it is possible to reduce this figure at some sites using either wind or solar power, but these resources are not available at all proposed UNAVCOM sites. Some sites will be required to operate from the prime power source alone.

If current technology is to be employed, three different power sources will be used in the UNAVCOM network; a dual redundant CCVT without an ecomomizer, a wind generator/single CCVT hybrid and a PV/single CCVT hybrid. ORMAT Systems Corp. in conjunction with different suppliers have already completed the development of these hybrid systems so all three types are available and have been fully tested. Very little will be gained by further testing of these power supplies in the UNAVCOM II station.

There is no question that a solution to the problem of power supply to the UNAVCOM II station is available. However, further development work currently underway at a number of companies will undoubtably lead to the production of a cheaper more efficient prime power supply.

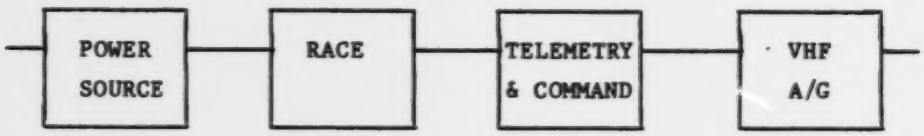
It is recommended therefore, that the purchase of the first remote power system be delayed until after the field trials of the UNAVCOM II station. This will decrease the capital costs of the UNAVCOM II system and save the UNAVCOM II program the equivelant of one year of fuel. The only restriction would be that tests of the UNAVCOM II station must be conducted at some site where reliable grid power is available.

3. RELIABILITY ANALYSIS

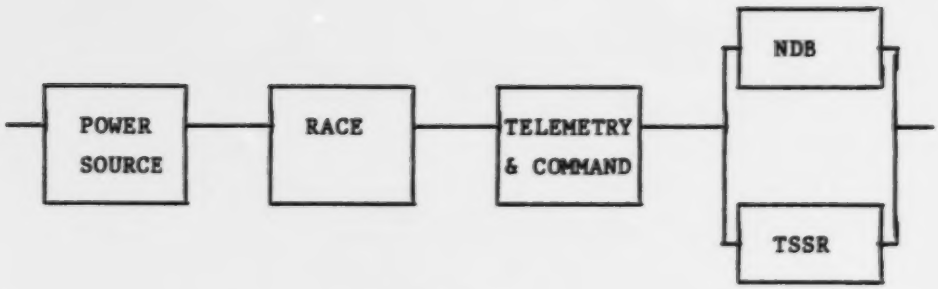
As outlined in Section 1.3 the UNAVCOM II station will be required to operate under Arctic conditions for a period of one year without routine maintenance and with a probability of .9 or greater that there will be no total failure of either the navigation or the communications subsystem during the same one year period. In order to assess the ability of the proposed UNAVCOM II station to meet these requirements, it will first be necessary to define what is to be considered a total failure of each subsystem.

From an operational viewpoint, a total failure of the navigation sub-system is a malfunction which prevents the transmission of the NDB signal as well as the TSSR automatic bearing and range replies. A failure of the communications sub-system is a malfunction which prevents the provision of reliable VHF air ground voice communications as required by the design specifications.

The simplified reliability diagram for the navigation and communications system shown in Figure 3.1 below indicate which equipment must be operating in order to fulfill these requirements.



Communications Reliability Chart



Navigation System

Figure 3.1 Reliability Chart

For the communications system to remain operational, the power supply, the communications backhaul system, the telemetry and command system and the VHF air/ground communications system must all be functioning. For the navigation system to remain operational, the power supply, the communications backhaul system, the telemetry and command system and either the NDB or the TSSR must be functioning properly.

The failure rate can then be used to determine the probability of one year's successful operation as follows:

Let R = reliability
T = period of operation = 8760
λ = failure rate

Then

$$R = e^{-\lambda t}$$

If the reliability of the system must exceed .9, then the maximum allowable total failure rate is 12×10^{-6} failures per hour.

The overall failure rate of the communications system can be obtained by adding the failure rates of each element. There are four elements so the average failure rate for each component or subsystem must be less than 3×10^{-6} failures per hour. This corresponds to an MTBF of over 300,000 hours. This is not a reasonable target.

However, if a single level of redundancy is added to each subsystem a total failure will only occur if a failure of a prime unit is followed by the failure of its backup before the first failure has been repaired. The probability of total failure is therefore obtained by multiplying the failure probability of each of the redundant units.

For example:

let P = probability of failure

so $P = 1-R$

if $1 - R_T = (1-R_1)(1-R_2)$

and $R_1 = e^{-\lambda t_1}$

$R_2 = e^{-\lambda t_2}$

$t_1 = 8760$ hrs.

$t_2 = 744$ hrs = Mean time to repair

then $1-R_T = (1-e^{-8760\lambda})\ (1-e^{-744\lambda})$

Solving this expression for λ indicates that, if the UNAVCOM system can be repaired within one month of a detected failure, an average MTBF of 20,000 hrs. for each unit in a fully redundant system is adequate to provide a reliability of .9. However, even though no total system failure will occur, failures may still be encountered in some of the primary units. Since there are four primary units each having an MTBF in the order of 20,000 hrs, the overall mean time to repair will be 5000 hours, or slightly over six months. This indicates that on average, two visits per site per year will be required.

SUBSYSTEM	MTBF	SOURCE	COMMENTS
NDB	20,000 - 30,000 hrs.	company records from out of date unit.	The old NDB is being replaced with similar though upgraded unit for which no data is available.
POWER SOURCE (ORMAT)	23,000 hrs.	company records.	Very large test sample.
RACE	?	N/A	Testing in the UNAVCOM II station will be required to produce this number.
T&C	20,000 hrs.	Parts count. Estimation based on 500 parts	The parts count indicates that this is a reasonable figure and it will therefore be a design target.
VHF A/G COMMUNICA-TION	30,000 hrs.	Estimate only	The Johnson radios do not have a recorded reliability. It is, however, easy to obtain replacement with 30,000 hr. MTBF.
TSSR	5,000 hrs.	Parts count. Estimation based on 500 parts.	The system has not yet been developed. This figure is the minimum acceptable.

Based on these figures the following reliabilities were calculated:

Communications - .93
Navigation - .91

Table 3.1 Reliability Estimates for System Components

If however, no attempt is made to repair failed units except during the yearly maintenance visit, the redundant unit will be required to operate for six months on average rather than one month. The reliability then becomes .75 with only one trip per year required. Clearly a trade-off exists between the number of yearly visits required, and the station reliability. We recommend that the decision on how to balance this trade-off be made on a site by site basis.

The results obtained in studying the navigation system were similar except that a total failure was defined as a failure of the NDB and TSSR. For this reason, no redundancy will be added to these units but a target of 20,000 hrs. MTBF still applies.

It was not possible to obtain accurate, measured MTBFs for each of the UNAVCOM subsystems. Some were obtained from field trials on a relatively small sample, others were merely estimated as a function of the total number of components. The following is a list of subsystem MTBFs and their source.

The accuracy of these estimates is questionable due to the lack of certain input data however, they do indicate that a reliability of .9 is an achievable goal.

One should bear in mind that the mean time between repair visits still remains low at 5,000 hrs.

With respect to the preliminary designs outlined in Section 2 both the RACE system and the Telemetry and Command system require special consideration here.

Marconi, the manufacturer of the RACE were not able to supply reliability records for their system and to the best of our knowledge, have not conducted a detailed reliability study. CAL does not have access to detailed design information and therefore cannot conduct an independent evaluation except through actual trials. Our UNAVCOM reliability study

indicates that it is very likely that a redundant RACE system will be needed but until the final decision to use RACE in the UNAVCOM network is made there seems little point in purchasing more than one unit. For this reason no redundant RACE system will be included in the UNAVCOM II station.

In the description of the Telemetry and Command system outlined in Section 2.5, there is no complete list of command functions that the T&C system will be required to perform. To compile such a list it will be necessary to consult the maintenance and service personnel assigned to operate the UNAVCOM station, but provisions have been made in the preliminary design to allow the microprocessor to perform virtually any simple command functions that are deemed necessary. You will notice however, that no mention has been made of redundancy requirements.

According to this reliability study, if the Telemetry and Command system is required to be operating properly for the rest of the station to perform correctly, a redundant microprocessor will be needed. If on the other hand no command functions performed by the T&C system are critical for the proper performance of the station, it is conceivable that the T&C not be considered in the station reliability analysis.

We strongly advise that before adding any remote command capability to the UNAVCOM II facility, the consequences of a control system failure be considered. The complexity and cost of a truly fault tolerant, self-assessing computer may outweigh the possible benefits, if including this function demands that a redundant Telemetry and Command system be used. For these reasons it is not recommended that a redundant microprocessor be included in the UNAVCOM II station.

4. SYSTEM COST ESTIMATES

The cost estimates for each subsystem described in section 2 are shown below.

SUBSYSTEM	MANUFACTURER	COST (CAN $, 1983)
EQUIPMENT ENCLOSURE	CHAMPION TRUCK BODIES/CAL	35,000
NON DIRECTIONAL BEACON	NAUTEL	47,500
VHF A/G COMMUNICATIONS	JOHNSTON	10,000
MARCONI RACE REMOTE TERMINAL	MARCONI	35,000
TELEMETRY & COMMAND	CAL	20,000
TSSR	CAL	100,000
POWER SUPPLY		
ORMAT/ORMAT	ORMAT	175,000
ORMAT/WIND	ORMAT/NORTHWIND	171,000
ORMAT/PV	ORMAT/CAL	195,000

Table 4.1 Cost Estimates for Future UNAVCOM Station

System integation and assembly charges will add another $25,000. Shipping charges will depend largely on location but the total installation cost can be expected to be at least $50,000.

The total capital investment for a single remote UNAVCOM installation will be approximately $500,000.00. In addition a number of manned central stations will be required. It is difficult at this time to predict this number because the performance of the RACE system remains an unknown. Assuming that these manned stations will be installed at sites where the necessary back haul equipment already exists as well as a building to house the UNAVCOM equipment, each site will cost about $100,000.00.

The total life cycle costs, ammortized over ten years, will be strongly affected by both the remoteness of the site in question and the frequency of repair and maintenance trips. Fuel cost estimates of $2.86/litre were obtained from Bradley Air Service based on a final staging distance of 300 km, using a Twin Otter. The cost per visit to a site at this distance was estimated to be $3,000. Based on these figures and a mean time between repair of 6 months (SEE SECTION 3) the following life cycle cost estimates were produced for each type of power supply:

ORMAT/ORMAT	
CAPITAL COST INCLUDING INSTALLATION	497,500
FUEL COST @ $13/GAL, 750 W	458,250
MAINTENANCE & REPAIR	90,000
	1,045,750
ORMAT/WIND	
CAPITAL COST	473,500
FUEL COST (PRIME SUPPLYING 10%)	45,825
MAINTENANCE & REPAIR	105,000
	644,325
ORMAT/PV	
CAPITAL COSTS	522,500
FUEL COST (PRIME SUPPLYING 20%)	91,000
MAINTENANCE & REPAIR	90,000
	704,150

Table 4.2 Life Cycle Cost Estimates

5. DEVELOPMENT PLAN

This section will outline a plan for continuing the development of the UNAVCOM II prototype from the preliminary design stage described in this report to the production of a fully tested station. This will involve the design, integration, assembly and testing of the station as well as the performance of a full year of operational field trials.

It was originally intended that these field trials be conducted at Lake Ennadai, a site in the North West Territories, selected by Transport Canada as a typical site in the full UNAVCOM network. CAL has recommended that a less remote site be chosen, preferably one where a reliable source of power already exists. There are three major reasons for this change:

1/ Conducting the field trials at a more accessible site will allow more frequent inspections and on site performance evaluations.
2/ The ORMAT CCVT has a well proven reliability record and doesn not require further field testing. It is our opinion that funds normally intended for the purchase of the CCVT and fuel would be better spent on controlled testing of the overall station.
3/ Assuming reasonable facilities are available at the less remote site, the installation and commissioning of the UNAVCOM station can be done at any time during the year rather than during the summer only.

In the interest of maintaining high reliability, high quality commercial equipment will be purchased wherever possible. This wili avoid the usual risks involved in developing specialized equipment. As outlined in Section 2, suppliers have been found for the following subsystems:

SUBSYSTEM	SUPPLIER
NDB	NAUTEL
VHF A/G RADIOS	JOHNSTON
EQUIPMENT ENCLOSURE	CHAMPION TRUCK BODIES
RACE HF COMMUNICATIONS LINK	MARCONI

Each of the units is available in both dc and ac versions. The UNAVCOM II prototype will initially be operated on ac however it will be necessary to ensure that each of the sub-systems purchased for the UNAVCOM II station can be easily reconfigured to operate off a dc power supply.

CAL will be developing the Telemetry and Command system, since it must be tailored specifically to this application. CAL is also investigating the feasibility of developing a low cost TSSR. Provisions will be made to include this system in the event that it is ready on time. The procedure used in performing these tasks is outlined in the following Statement of Work.

WORK STATEMENT

1) Carry out a detailed design of the UNAVCOM II station based upon the preliminary design presented in this report. This will include the design of any required data collection and analysis facilities needed for field testing.
2) Hold a preliminary design review.
3) Procure the necessary equipment to develop and test a prototype UNAVCOM II station.
4) Build and test bread board versions of all CAL developed subsystems.
5) Develop all software required to operate the UNAVCOM II station.
6) Build final prototype versions of all CAL developed hardware.
7) Conduct environmental tests on all units in accordance with MIL-810-C.
8) Integrate, assemble and test the complete UNAVCOM station and prepare an evaluation report for delivery to Transport Canada. This report will be include the following:

    a) Environmental Test Reports;
    b) Performance Test Reports;
    c) As Built Drawings;
    d) Preliminary Operation and Maintenance Manuals.

9) Hold a review meeting prior to shipment to a remote site to perfrom acceptance inspections of UNAVCOM equipment.
10) Conduct an operation and maintenance seminar for local staff and system users.

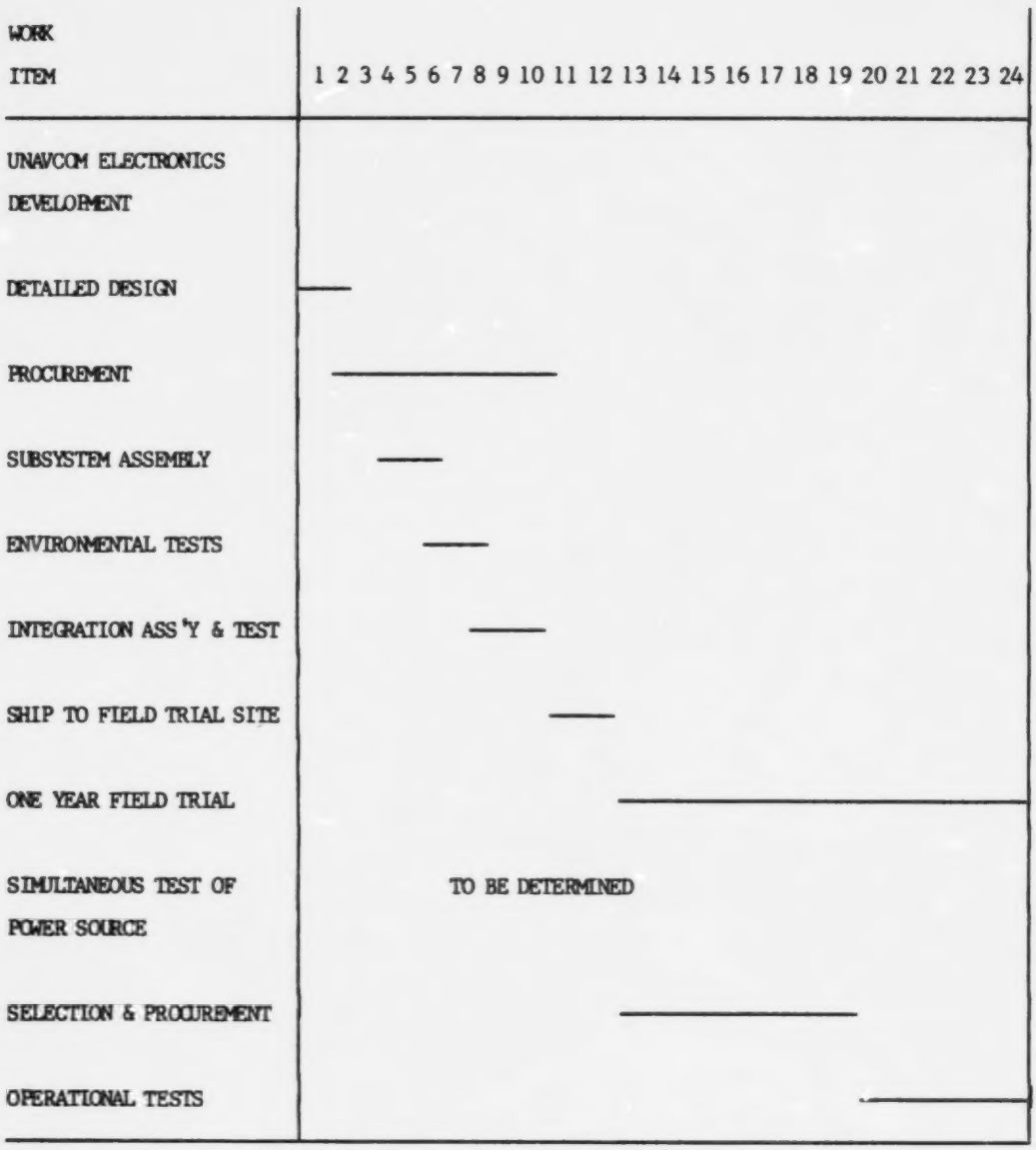
*The above work has been referred to as Phase II of the UNAVCOM II program. The following is a work statement for Phase III.

11) Prepare the proposed test site for the installation of the UNAVCOM station.
12) Ship all necessary equipment to the installation site.
13) Install the UNAVCOM station. This will include the erection of the NDB tower and the connection of the electronics to the local power grid.
14) Prepare the central manned station for the installation of the MASTER RACE STATION EQUIPMENT.
15) Ship all required equipment to the manned station.
16) Install and test the manned station equipment.
17) Commission the entire system and begin the one year field trial.
18) Conduct routine site inspections every 2 months.
19) Prepare an evaluation report on the performance of the UNAVCOM II station.

Canadian Astronautics Ltd. has already submitted a proposal for the work defined as Phase II. The contract is currently under negotiation but the total cost is expected to be under $500,000. The cost of Phase III will be highly dependant on the location of the site which will be selected by Transport Canada. A reasonable estimate of the cost is between $100,000 and $150,000 for the third phase.

The proposed schedule for this work is shown in Figure 5.1.

Figure 5.1 Project Schedule For
Future UNAVCOM Development


WORK ITEM
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
UNAVCOM ELECTRONICS DEVELOPMENT
DETAILED DESIGN
PROCUREMENT
SUBSYSTEM ASSEMBLY
ENVIRONMENTAL TESTS
INTEGRATION ASS'Y & TEST
SHIP TO FIELD TRIAL SITE
ONE YEAR FIELD TRIAL
SIMULTANEOUS TEST OF POWER SOURCE
TO BE DETERMINED
SELECTION & PROCUREMENT
OPERATIONAL TESTS

6. CONCLUSIONS AND RECOMMENDATIONS

The following is a point by point evaluation of the proposed UNVACOM II's ability to meet the specifications as laid down by Transport Canada.

1/ The system is required to provide reliable VHF air ground communications 95% of the time anywhere within a 160 km radius of the site. For the system to do this both a VHF link from the pilot to the remote station and an HF link from the remote station to a central manned station must be established. The VHF equipment in the UNAVCOM II station will be mounted on the NDB tower and no problem is anticipated with this equipment. The MARCONI RACE HF link however has not yet been thoroughly tested, and has been recommended for use in this system primarily due to its low cost. Our major concern with this system is its availability especially during ionic storms. Careful evaluation of this system during the field trial will be required before recommending its use in the operational UNAVCOM NETWORK.

2/ The system is required to supply NDB signals towards which bearings can be obtained accurate to ±5° for 95% of the readings taken anywhere within a 100 km radius. This objective was achieved in the UNAVCOM I station and the equipments proposed for the UNAVCOM II station are upgraded versions of the UNAVCOM I equipments.

3/ The station will be required to operate from an internal power source, with no connection to the regular electric power grid. The ORMAT CCVT, with wind or solar economizer, will allow the system to do this. However, for reasons discussed in Section 2, no power supply will be provided with the UNAVCOM II prototype.

4/ The station must operate in the field under Arctic conditions for a period of one year without routine maintenance and with a probability of .9 or greater that there will be no total failure of either the navigation or communications sub-systems during the year. The reliability of certain system components in particular the RACE system cannot be verified. However indications are that this reliability figure of .9 is well within the capability of the system providing each subsystem has a redundant unit and repairs to a first failure can be effected within one month. This reliability is not greatly affected by routine maintenance but initial calculations indicate that unscheduled visits to repair damaged but still functional units, will be required every six months on average.

5/ The system must also provide 99.9% availability throughout the year for both NDB bearings and the VHF bearing replies. If the system can be reparied within 30 days, the low scheduled maintenance requirements of the NDB system will allow the NDB to provide 99.9% availability provided the MTBF is 20,000 hours. as the manufacturer claims. The MTBF of the TSSR however is not yet known. It is reasonable to expect it to match the NDB figures, however we cannot verify this yet.

The anticipated 10 year life cycle cost for a single UNAVCOM station is expected to range between $700,000 and $1,100,000 (1983 CAN) depending on the availability of wind or solar energy. These costs are high, but would be considerably reduced if the basic UNAVCOM specifications were altered.

The following changes have been included as susggestions for review by Transport Canada:

1/ The reliability objective of .9 has placed restrictions on the selection of the power supply and forced redundancy on nearly all sub-systems. If the reliability objective were reduced to say .75, many of these restrictions would disappear. For example, the main reason for rejecting the Mechron cycle charge diesel system was its questionable reliability. If the reliability were relaxed this system could be used and considerable savings would be realized. This is quite reasonable if a UNAVCOM station is considered in its context as a component of a network of stations. A single station failure will not result in the total loss of services, if it is correctly reported and pilots in the area are warned and, if possible, rerouted.

2/ If the operational availibility requirement of the Navigation aids were lowered, a mode of operation could be envisioned where a base load of the 200 watts required by the communications system would be produced by a highly reliable prime power source while the remaining power would be produced by a soft energy source on a partial availability basis. A 200 W TEG coupled with either a wind generator or photovoltaic system could then be used to produce the required power at a significantly lower price. The inconvenience to pilots could be reduced by allowing VHF requests to turn on the NDB or TSSR as required.

In areas of marginal wind and sunlight, a power supply using a Cycle-Charge Diesel with a propane TEG back-up could also be used to reduce cost.

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APPENDIX A

EVALUATION OF UNAVCOM II

NDB REQUIREMENTS

REPORT PREPARED BY CAL'S MICROWAVE GROUP
UNDER INTERNAL SUBCONTRACT

A. NON-DIRECTIONAL BEACON SUBSYSTEM

The study of this subsystem can be divided as follows:

1) Transmitter and Control Unit
2) Antenna Tuning Unit
3) Antenna Unit.

A.1 The Transmitter and Control Unit

A study of the operation experience of the NAUTEL NEL7703 unit as well as evaluation of its design and circuits qualifies the unit to be used again in UNAVCOM-II.

However, by discussions to NAUTEL it was found that NAUTEL is developing a newer unit called ND500. This unit is intended for remote unattended applications and its power consumption is half as much as NEL 7703. This unit will be available by early spring 1983 and its application in UNAVCOM-II, instead of NEL 7703, is highly recommended.

Following, a comparison is made between the two units, which highlights their differences which are of interest in UNAVCOM project.

The new unit (ND500) does not have four 25 watt power amplifiers to add up to 100 watts, which provides the fail-soft feature for NEL 7703. Instead, it has two independent power amplifiers (with adjustable power from 50 to 125 watts) which can work as automatically selected main/standby units. This provides more reliability if maximum power is always demanded from the unit.

The new unit uses high efficiency Class D power amplifiers while NEL 7703 uses Class A power amplifiers. This is the reason why the power consumption of ND500 is half as much as NEL 7703. For a 100 watt output power ND500 uses about 200 watts of prime power (using dc power input) while NEL 7703 uses at least 400 watts under the same conditions.

ND500 is packaged in a lockable weather proof box (seam welded steel box with fully gasketed door) which can be mounted outdoors and possibly on the NDB antenna structure itself, like the antenna tunning unit box. Therefore, the need for a heated room for NDB is eliminated which is a cost saving in the total UNAVCOM system. NEL 7703 unit is packaged in a rack and cannot be installed outdoors.

The physical size and weight of ND 500 is about 2.5 times less than NEL 7703 which provides more portability for the equipment. The units compare in size as follows:

MODEL	HEIGHT	WIDTH	DEPTH	WEIGHT
ND 500	61 cm	50.8 cm	23.5 cm	45 kg
NEL 7703	125 cm	75.0 cm	61.0 cm	118 kg

ND 500 has built-in remote control features while these features should be added to NEL 7703.

ND 500 is specified for -40°C to +55°C, 0-95% humidity while NEL 7703 is specified for -10°C to +55°C, 0-95% humidity. This also eliminates the need for a semi-heated room for NDB.

Other features of ND 500 are better or at least same as NEL 7703. On the other hand, there is no field experience for ND 500. However according to NAUTEL the standards to develop ND 500 are much higher than NEL 7703 and it should prove as reliable as NEL 7703.

A.2 Antenna Tuning Unit

The automatic antenna tuning unit, which matches the NDB transmitter unit to the antenna, did not perform its function satisfactorily. This was because the unit provides the reactive compensation, necessary for putting the antenna on resonance, by variable inductances. These variable inductances are controlled by the mechanical movements of ferrite cores by an electric motor and a spiral-shaft/gear system. The spiral-shaft/gear mechanism failed due to frost/ice.

The issue was discussed with NAUTEL. It was found that they had noticed this problem as well, and in the antenna tuning unit developed for ND 500 (model NX 400 TUB), the core moving mechanism is permanently oiled and sealed to avoid failure due to frost.

A non-mechanical ATU, however, is highly recommended for this type of application.

A design based on such an idea is presented in the next section. It is basically a design modification to NAUTEL's ATU which replaces the servo mechanism used to alter the loading coils by a microprocessor controlled feed-back loop which switches different inductance of loading coils into the antenna circuit. This design features the following:

1) No mechanical movement is envolved except for the switching relays which are hermetically sealed. Also the design can be futher refined by replacing the relays by solid-state switches such as diode switches. This would be the goal if CAL is awarded the responsibility to develop such a unit.

2) The design consumes less power than the mechanical tuuner. This is because of the elimination of the servo motor and the driver amplifier.

3) The design is less costly. A cost analysis given shows it would cast around $2873 each (for quantity of 30 predicted for UNAVCOM), while NAUTEL's tuner is selling for over $3500 out of the production line.

4) The design is more reliable by nature because of non-moving parts which are not subject to wear and breakage.

5) In terms of physical size and weight it is also smaller and lighter which makes it more desirable for the UNAVCOM application.

A.2.1 Digital Antenna Tuning Unit

This unit matches the 50 ohm trammitter output to an antenna having radiation resistance of 2 to 30 ohms and capacitance of 250 to 1250 pF. It automatically compensates for the variations in the antenna reactance caused by the changes in the operating environment. Also forward and reflected powers as well as the antenna current are metered.

The proposed unit is block diagrammed in Figure 1. The input current and voltage are sampled and fed to the phase detector. The output of this detector is fed to the microprocessor which controls the inductive loading to the antenna. Proper amounts of the compensation inductance is switched in to give a phase angle as close to zero as possible.

The matching transformer steps down the impedance by the proper tap selection, which can be automated as well. This can be done by inputing the voltage and current detection to the microprocessor, calculating the impedance and comparing it to the transmitter output impedance (50Ω) thus deciding which tap to select. Normally the radiation resistance of antennas used for NDB is fairly constant with the environment, for a particular installation, a manual selector (rather than automated) is sufficient.

The metering of the forward and reflected power and antenna current is provided by digitizing these currents from the detecotrs, and inputting them to the microprocessor. The microprocessor can decode and send them to the numeric display for the particular metering requested by the key pad.

The reactive loading components Z_1, Z_2, will be chosen in proportion to 1, 2, 5, 10, 20, 50 so that tuning can be done with a minimum number of inductors.

A.2.1.1 A simplified Economic Tuner

For the UNAVCOM-II NDB, a simplified version of ATU of Figure 1 is proposed. Such a simplification is shown in Figure 2. The features are as follows:

1) The impedance matching transformer is set manually for the particular antenna used.

2) Only reactive loading compensation is automated by a simple phase detector and a single-chip microprocessor like INTEL 8748 etc.

3) The compensation reactive elements, to be switched in, are inductors having values of L_0, $2L_0$, $5L_0$, $10L_0$, $20L_0$, and $50L_0$. Where L_0 is calculated later to be approximately 3 μH. This provides 2% accuracy in tuning because:

$$\frac{L_0}{L_0 + 2L_0 + 5L_0 + 10L_0 + 20L_0 + 50L_0} \times 100$$

$$= 1.12\%$$

4) The metering is done by passive circuits, similar to UNAVCOM-I metering, consisting of transformers, diodes, resistors, and mechanical meters. This adds to the system simplicity, reliability, as well as insentivity to the lightning hazards.

In this circuit the design philosophy is simplicity, reliability, and economy. Other versions of Figure 1 which provides digital metering could be considered but with higher cost.

The circuit and timing diagram of the digital phase detector used is given in Figure 3 and 4, respectively.

The program flow chart is presented in Figure 5.

POWER AND COST

The power consumption and cost of each part of the unit is estimated to be:

SUB-UNIT	POWER CONSUMPTION	COST
voltage sensor	less than 0.1 W	$ 10.00
current sensor	less than 0.5 W	$ 30.00
Digital phase detector	less than 2.0 W	$ 60.00
microprocessor + clock	less than 3.0 W	$ 100.00
matching transformer	less than 0.5 W	$ 50.00
FWD/REF metering	less than 1.5 W	$ 150.00
Antenna current sensor & meter	less than 0.5 W	$ 60.00
load coils (5)	0.1 W max	$ 150.00
relays (or diode switches) (11)	0.3 W	$ 220.00
Relay drivers (11)	0.1 W	$ 33.00
Antenna feeder	0	$ 50.00
Air Gap	0	$ 30.00
power supply (12 to 5V regulator)	5.0 W wasted	$ 100.00
connectors		$ 100.00
box and hardware		$ 200.00
PCB		$ 30.00
labour to make and test one		$ 500.00
Amortization of the development cost over 30 units as such		$1000.00
TOTAL	less than 18.0 watts	$2873.00

CALCULATION OF REACTIVE LOAD

Only inductive elements should be switched in since the antenna is dominantly reactive. The values of the reactances are chosen in proportion to 1, 2, 5, 10, 50, ... numbers to minimize the number of inductors as well as the number of switching relays. Therefore, to calculate the reactance ii suffices to calculate the value of L_0 (Figure 2).

The antenna is at resonance if $\frac{1}{jWC} - jWL = 0$,
where:

W = frequency of NDB operation
C = antenna capacitance (maximum 1250 pF is the specification of NAUTEL ATU is used)
L = total inductors switched in.

Thus we can write:

$$\frac{1}{WC} = WL$$

or

$$L = \frac{1}{W^2C}$$

for maximum compensation

$$L_{max} = \frac{1}{(2\pi \times 288.15\ kHz)^2 \times 1250\ pF}$$

$$= 245\ \mu H$$

This L_{max} consists of all inductors switched in, i.e.:

$$L_0 + 2L_0 + 5L_0 + 10L_0 + 20L_0 + 50L_0 = L_{max}$$

or

$$88\ L_0 = 245\ \mu H$$

$$L_0 = 2.8\ \mu H$$

These coils should be made in a way that they have the lowest resistance possible, since any resistance would absorb the useful power away from the antenna itself. Also, they should be mounted in a way that mutual couplings among them are avoided.

A.3 THE ANTENNA UNIT

The evaluation of the antenna unit used for UNAVCOM-I; i.e. the umbrella top loaded tower, is a good selection for the task, from the economic point of view. Modifications, as discussed below, will help to increase the antenna radiation efficiency.

The antenna dimensions are given in Figure 6; the following modifications are recommended.

1) The guy radius, d, should be increased to at least as much as the antenna height h.

2) The proportion of s/h should be selected to produce maximum radiation resistance. This means s/h should be increased to about 0.45.

3) If possible the number of guys should be increased to more than 3.

4) The loading coil mounted in the higher section of the tower is not needed. A better designed antenna would be quite satisfactory without this coil. Also, elimination of this coil would provide reduction in the antenna cost.

5) The ground radials are well selected in length. The number of these radials are quite sufficient (one per every 6 degrees), although a reduction in their number is even recommended, for economy, especially for regions of good ground conductivity.

As a better antenna alternative, use of a flat-top antenna units, similar to Polestar antennas of Figure 7 is recommended. This is because such a design reduces the antenna reactance without degrading and reducing the radiation resistance which is not totally achieved by the umbrella top loading.

This type of antenna could be purchased, as a standard unit, from Polestar with custom ordered top winding for the frequency of operation. The price is about $14500 for PA 90 B model. It features the following:

1) Aluminum tower construction which provides a lot of transportability for the unit. Further, the antenna could be completely assembled at ground level and is hoisted to vertical position by means of a hand operated winch. This is particularly attractive for the remote installations where heavy machinery is not available.

2) Ninety percent of the loading coil, necessary for the reactive compensation, is located at the top and is custom designed for the frequency of the operation. The other 10% is contained in the Automatic Tuning Unit. Such an approach makes the unit more insensitive to the tuner unit malfunctioning and provides better radiation efficiency.

Polestar also is offering a servo mechanical ATU with sealed motor, for about $3000 in price. However, a non-mechanical ATU of the type discussed in Section 2.1 is recommended with total tuning coil 10 times less than what is needed for an ordinary umbrella type antenna.

CONCLUSION

As a result of the study, the following is recommended for NDB system.

1. For transmitter, NAUTEL ND-500 unit is recommended

2. For Automatic Tuning Unit, CAL's simplified digital ATU, of Section 2.1.1, is recommended

3. For the Antenna, the Polestar antenna is recommended

The cost and power estimates for the equipment is as follows:

ITEM	POWER	
Transmitter Unit	200 W	$11,000
CAL's ATU	20 W	$ 2,873
Polestar Antenna	Power used by hazard lights	$14,500
TOTAL	220 W	$28,373

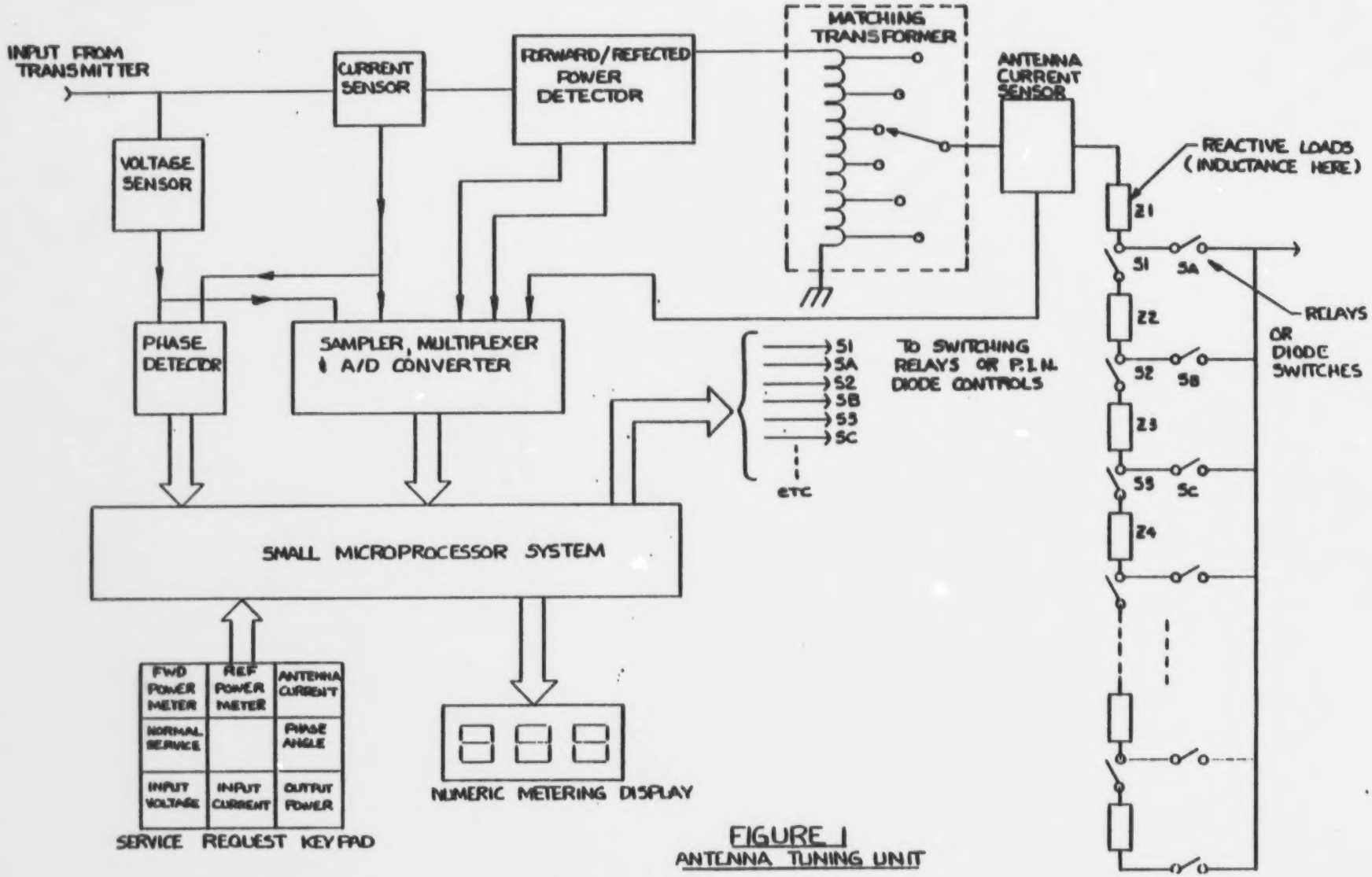


FIGURE 1
ANTENNA TUNING UNIT

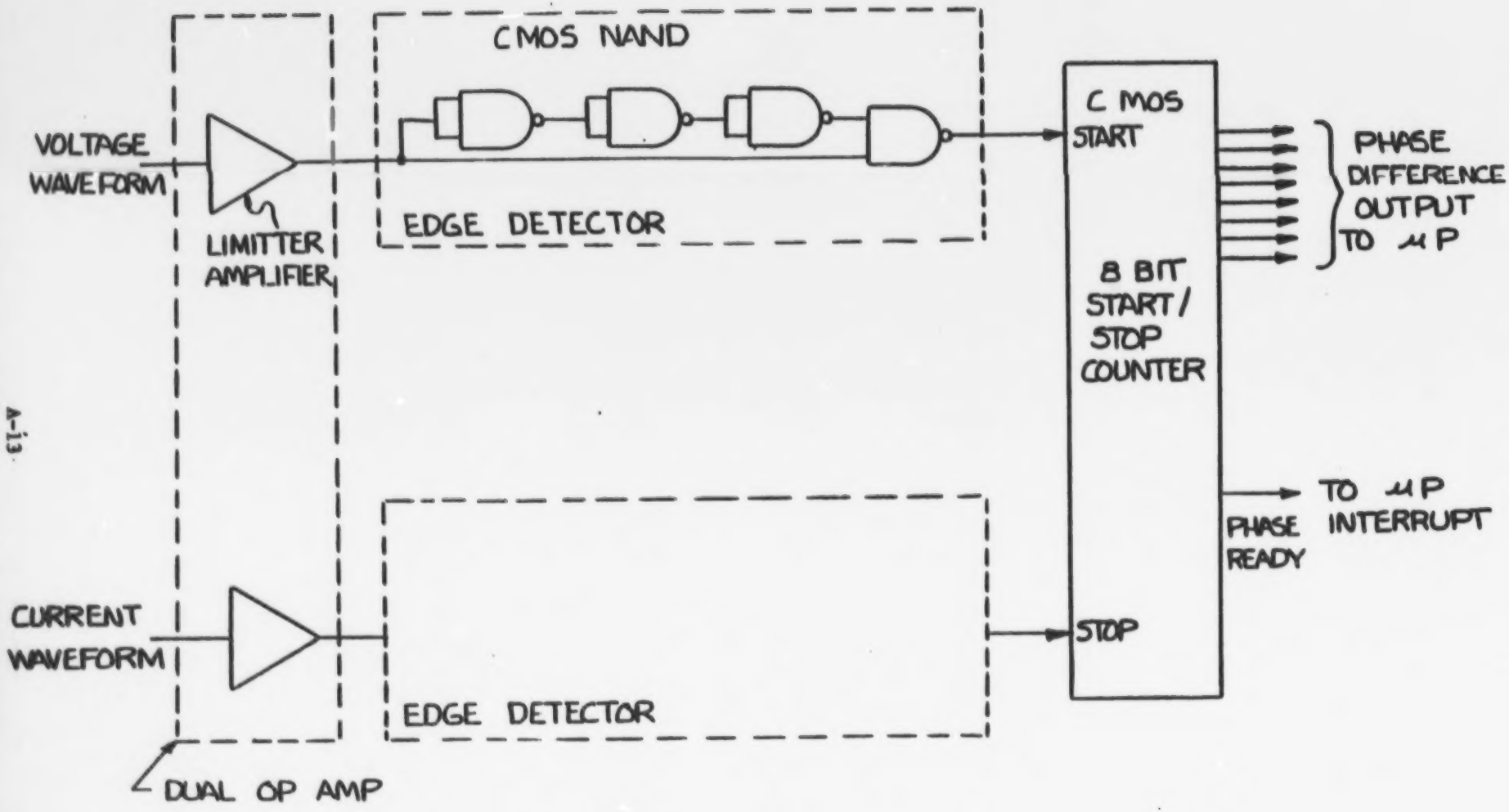


FIG 3. DIGITAL PHASE DETECTOR

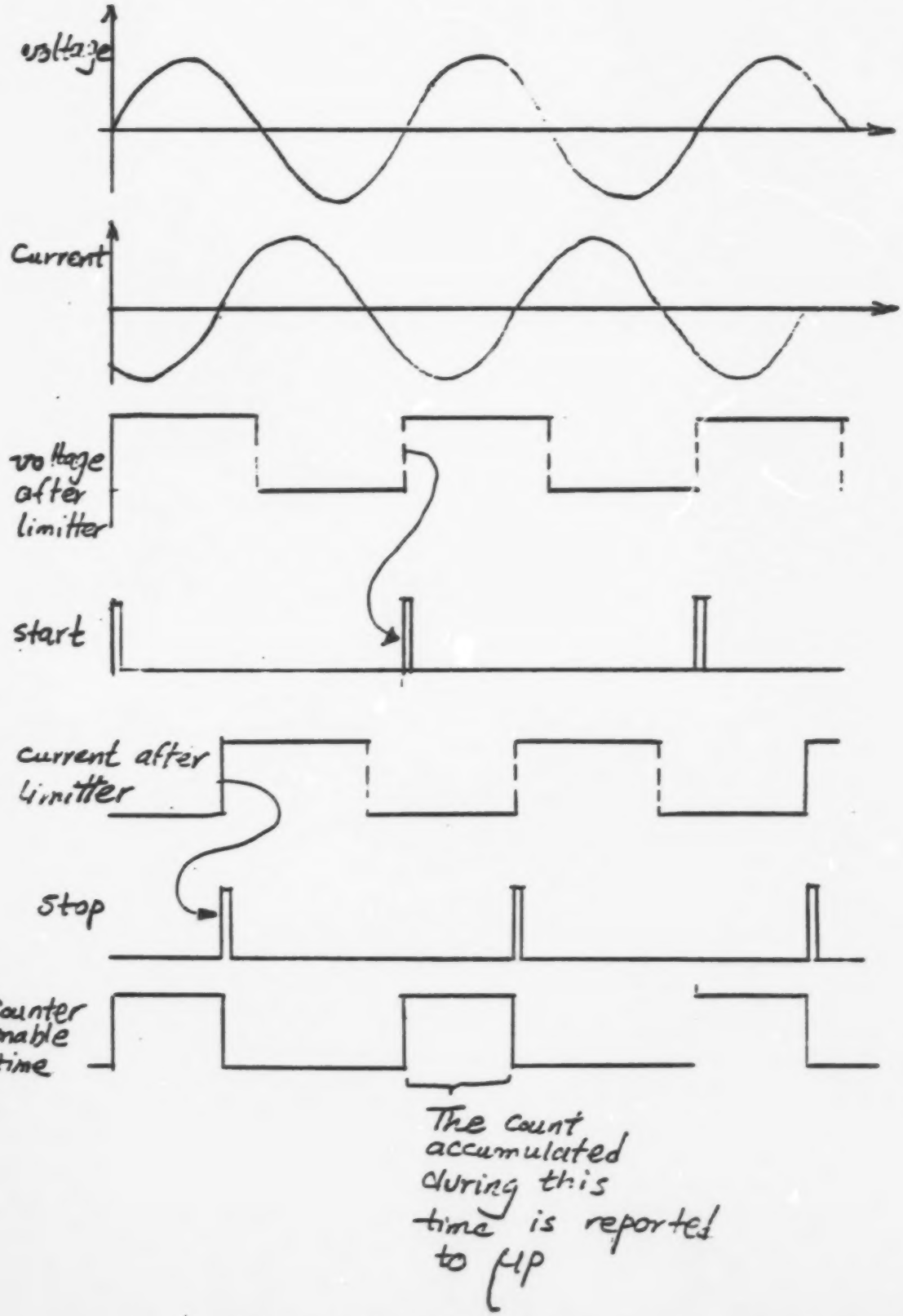


FIG. 4 TIMING DIAGRAM OF THE PHASE DETECTOR

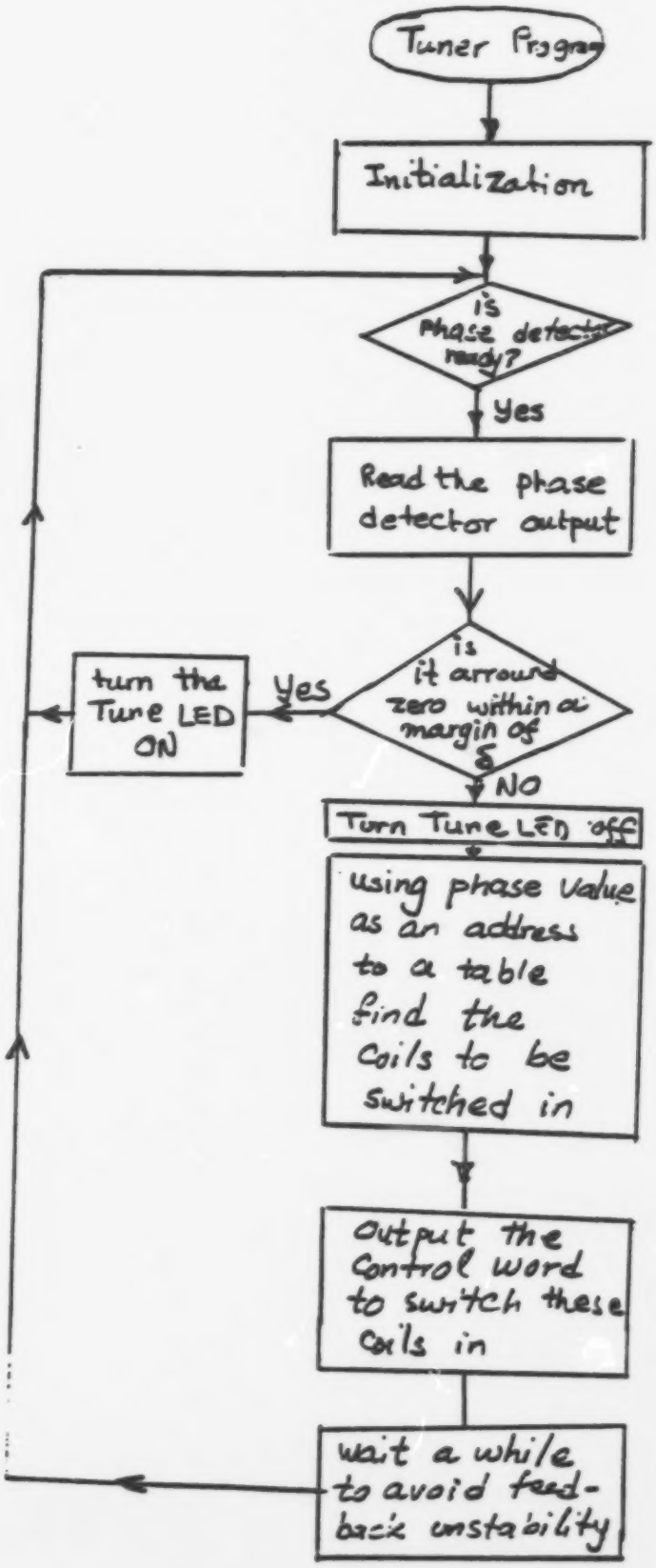

Tuner Program
Initialization
Is Phase detector ready?
Yes
Read the phase detector output
Is it arround zero within a margin of 5
Yes
turn the Tune LED ON
NO
Turn Tune LED off
using phase value as an address to a table find the coils to be switched in
Output the control word to switch these coils in
wait a while to avoid feed-back instability

FIG. 5 PROGRAM FLOW-CHART OF THE TUNER µP

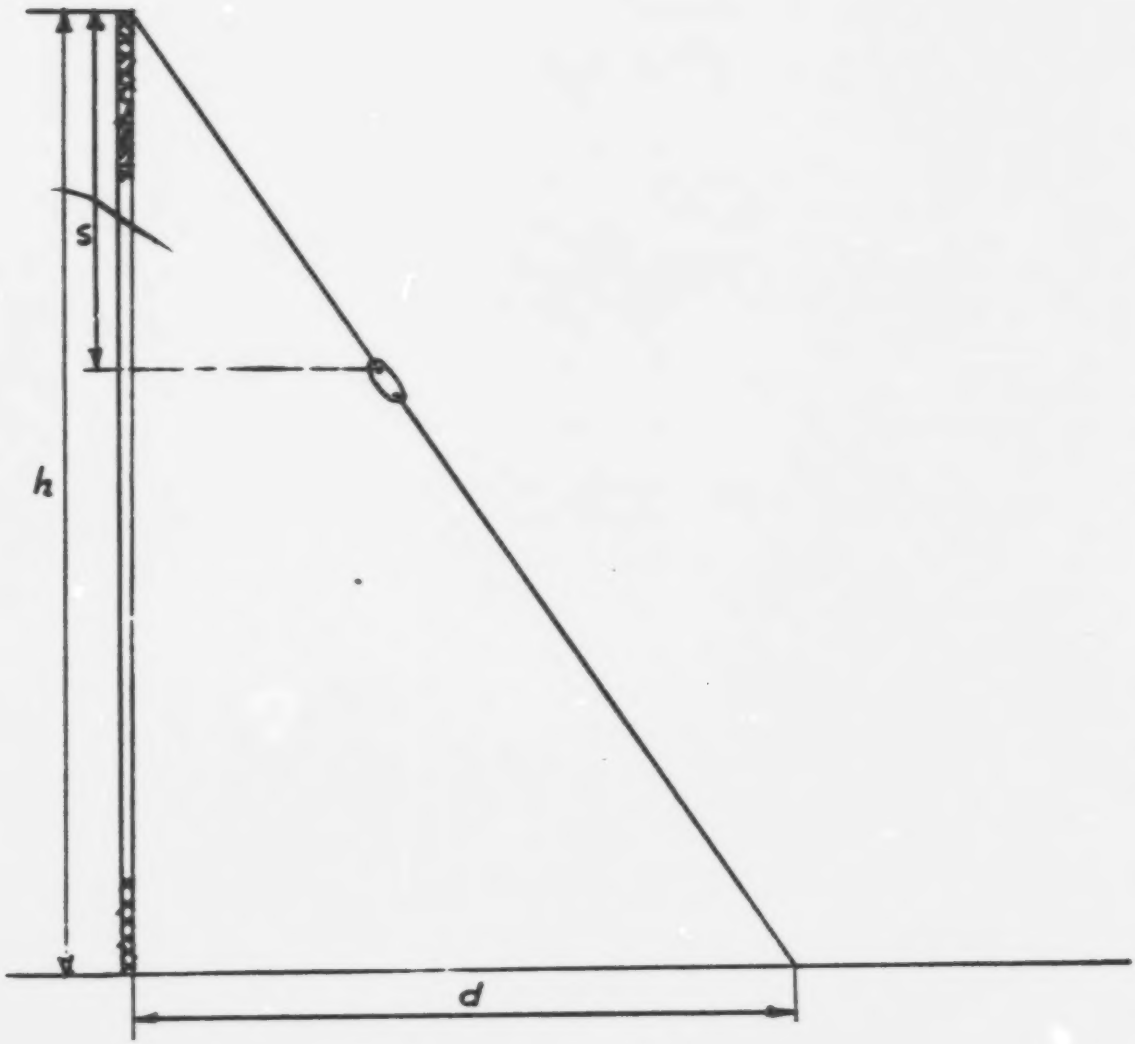


FIG.6. NDB ANTENNA DIMENSIONS

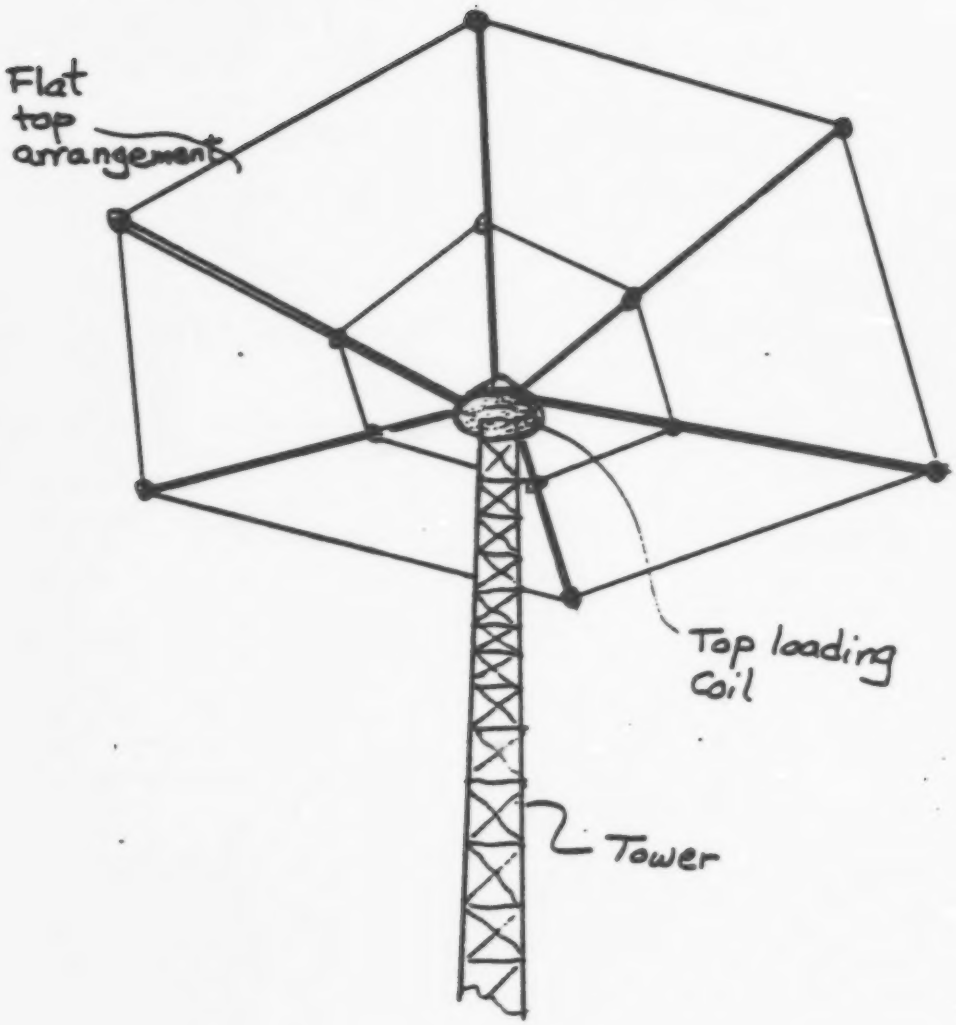


FIG.7 FLAT TOP POLESTAR ANTENNA

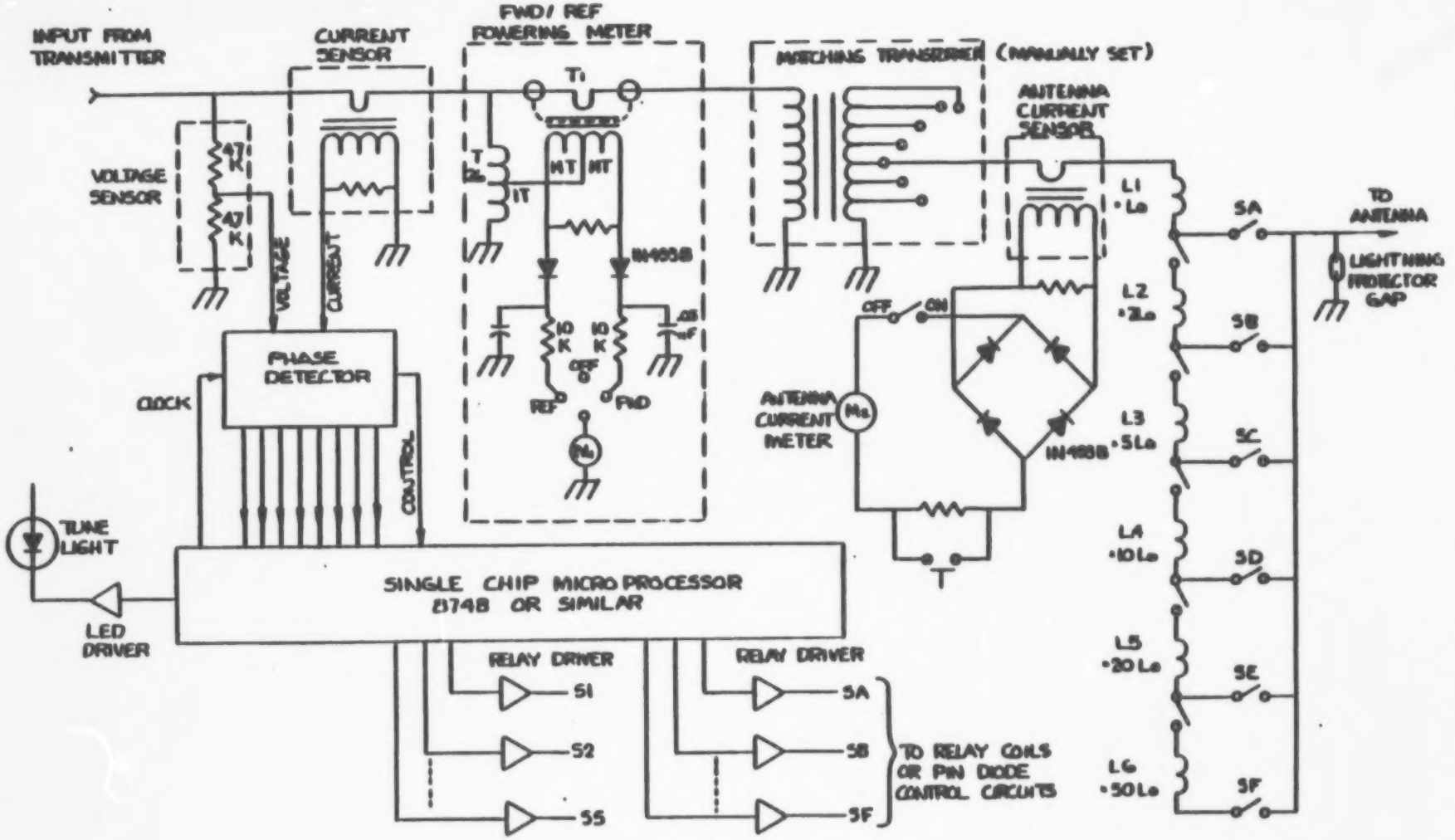


FIGURE 2

SIMPLIFIED ANTENNA TUNING UNIT PROPOSED FOR UNAVCOM II

C. DATA COMMUNICATION

- Messages are sent from a Universal Synchronous Receiver Transmitter (USRT) for bit-serial, synchronous communiciations

- Data is transmitted in a NRZ format at 9600, BAUD, changing on the positive transition of the clock. (Baud rate is selectable from 2400, 4800, 7200, and 9600).

- The clock and data are transmitted via RS-232C drivers for high noise immunity.

- Data messages are transmitted as a contiguous character stream, bit synchronous with respect to the clock, and character synchronous with respect to the sync characters initializing each message.

- Two sync characters are sent at the start of each message for a bi-sync mode of operation.

- An end of message (EOM) character, consisting of all ones is sent at the end of each message.

- Fill characters are sent, when there are no messages, to maintain character synchronization.

APPENDIX B

EVALUATION OF VARIOUS COMMUNICATION BACKHAUL SYSTEMS

FOR UNAVCOM II

REPORT PREPARED BY HICOM

UNDER SUBCONTRACT TO CAL

B. INTRODUCTION

Hicom Design Ltd. (HDL), under subcontract to Canadian Astronautics Ltd. presents the following report investigating methods of establishing a rearward communications link and a telemetry remote monitoring and control system for Transport Canada's proposed UNAVCOM II project.

The objective of the subcontract was to investigate alternative methods of a rearward communications link and as assess each system with regards to suitability and efficient prime power requirements.

The subcontract also requires that the telemetry remote monitoring and control system be further investigated. The result was to make a preliminary design of a prime power efficient rearward link which incorporated a telemetry remote monitoring and control system.

B.1 Rearward Link

B.1.1 Introduction

The Rearward Link is to provide from the UNAVCOM II suitable communications for either voice from an aircraft pilot request or telemetry data indicating the status of the remote site. This link would terminate at a manned control station. The manned control station would provide a forward link for voice communication and remote control of various functions of the UNAVCOM II.

The objective of the study was to evaluate several different methods of rearward communication links with regards to:

a) availability
b) prime power requirements and reduction techniques
c) cost-effectiveness
d) suitability

The most immediate solution to the rearward communication links is to use the existing 4/6 GHz domestic satellite system. However, this may not be the most cost/effective solution, as outlined in section 3.5. Therefore, other alternatives were investigated and these are outlined below:

a) Meteor Burst Communications
b) Radio Telephone with Automatic Channel Evaluation (RACE)
c) Mobile Satellite System (MSAT)
d) 12/14 GHz Satellite System

B.2 Meteor Burst Communications

This form of communications link is based upon the phenomenon of reflecting radio waves off of ionized trails left by micrometeors as they enter the atmosphere and burn up (see appendix for further information). The range is typically 2000 kilometers but it can have wait times of a few hundred milliseconds to a couple of minutes depending on the time of day, time of year and system design. The main transmitter sends a continuous coded signal and when the transmission path is acquired the addressed remote site sends back data via the same path until the path becomes too degraded to be of further use. This type of system is suited to a remote data collection platform where continuous real time data transmission is not required. Typical remote prime power requirements are in the order of 500-600 watts when transmitting although the duty cycle is low. The remote system basically stores the data until the link is established by the main control station. At this time the remote site will "burst" the data back to the main site. The system would be ideally suited for a remote monitoring data telemetry system but not for a real time voice communication system. Cost is low for hardware and there are no recurring circuit fees. The system would not be appropriate for a direct aircraft pilot to Area Control Centre voice communications.

B.3 Radio Telephone With Automatic Channel evaluation (RACE)

B.3.1 Introduction

HF communications has been in existence for some time. The main disadvantages of current HF Telephone systems are as follows:

- The inherent variability of the ionosphere;
- The need for skilled operators;
- The necessity of identifying a frequency providing adequate transmission for a given call;
- The difficulty of effective interconnection to an automatic telephone system.

Typical propagation paths depend greatly on the frequency, transmitted power, receiver sensitivity, modulation techniques, ionospheric storms daytime, nighttime, sun spot activities, etc. However, in most cases there is at least one frequency in the HF bands that is generally usable. The trouble is finding that frequency.

Optimum frequencies tend to be high during the day (10 MHz to 20 MHz) while at night the optimum frequencies are lower (5 MHz to 10 MHz).

Typical transmission paths vary from miles to several thousand miles depending on the number of hops. For the UNAVCOM II system the longest distance to a manned ACC would be less than 500 miles. The RACE system described below is a fully automatic HF Radiotelephone system which appears to hold promise for the UNAVCOM II rearward communications link.

B.3.2 Availability

The RACE system is a HF radio technique which has a real time ionospheric polling system which continually evaluates up to 8 different receive frequency channels for best reception and stores that channel number in memory. The Master Station transmits an idle message on each fequency, up to 8 from 2 to 24 MHz, every 2 seconds and each Remote Station evaluates the reception. This means that the Remote Station is always in the standby mode until it is requested to transmit.

With the real-time channel evaluation system designed for the RACE system, a clear frequency, if available, is automatically selected when a call request is made. An additional feature for voice communications is the use of the Syncompex speech processor using digital companding techniques. Its noise suppression characteristics are used when the channel selected is still rated as noisy by the signal quality detector.

These systems are presently available from Marconi (see appendix). The average time to set up a call using the system as a PBX is about 6 seconds. The setup time can be reduced in an application such as UNAVCOM II since in a PBX system there is a fair bit of telephony protocol which uses time.

The power requirements of the remote site for voice communicaitons when transmitting is in the order of 75 watts. During idle periods this power consumption falls to less than 10 watts. The system has been installed and used in Western Canada, Eastern Canada and Baffin Island but no performance records are available. The following are the results of a computer simulation aimed at predicting the performance of the RACE system:

65 Km path	99.9% availability
965 Km path	98.3% availability
270 Km path	98.7% availability
490 Km path	99.2% availability

During each trial a major goemagnetic storm caused a blockage of 6 hours. However, for 98% of the time there was at least one of the eight frequencies available. The cost of a single channel system FOB factory would be in the neighbourhood of $20,000.00 with installation and system set-up charges extra.

The advantage of the system is low capital cost, low power consumption and no circuit/equipment leasing charges. The disadvantage is that the availability depends upon such things as distance, RF power, geomagnetic storms, etc., as previously indicated.

In the appendix, more information is available, including an optimization computer simulation by Marconi. This shows a propogation model, best frequencies and antenna systems for a RACE system installed in Frobisher Bay to serve the UNAVCOM II in that area.

B.4 MSAT (Mobile Satellite)

B.4.1 Introduction

The Canadian Mobile Satellite program, MSAT, is a program to develop public mobile-satellite communication services at 800 MHz frequency. Phase A studies have been completed by the Department of Communications and work has now started on Phase B (Project Definition) involving economic studies, system definition and technology development. The planned launch of MSAT is 1987 will be followed by a post-launch experimental program and semi-commercial service by 1990. The commercial viable system is expected to evolve in the early 1990's.

B.4.2 Suitability

At first glance the MSAT system appears to be a viable solution for the UNAVCOM II rearward communictions link. the satellite footprint covers all of Canada and, therefore, the UNAVCOM II locations will have access to the satellite. There does not exist at present an MSAT mobile earth terminal. However, DOC, in phase B, is letting contracts to design and develop mobile terminals using three different modulation techniques, amplitude companded single sideband (ACSSB), pitch-excited linear predictive coding (PELPC) and narrow band frequency modulation (NBFM).

These terminals will be evaluated by DOC to determine which technique would contribute the most to reduced band-width and power requirements. The significance of power and bandwidth reduction techniques becomes clear when one realizes that there is only 4 MHz of satellite transponder available, i.e. most satellite systems have 10 times that bandwidth per transponder.

Although the earth terminal has not been developed yet, mobile communications have existed for many years and that technology has direct applications. Based on the present mobile systems and future development costs, cost estimates have been produced that show a mobile earth terminal should be sold at less than $5,000.00 with tariff charges of $1.00 to 1.50 per minute, all 1982 dollars.[1] For a fixed earth terminal, the costs may be slightly higher due to using a larger antenna to reduce the RF amplifier power requirements. The prime power requirements of the earth terminal are estimated to be less than 80 watts when transmitting.

---

[1] "User Cost Benefit Study for a Mobile Satellite Radio System" Systemhouse Ltd., Ottawa DOC-CR-SP-82-027-028.

B.4.3 Problem Areas

MSAT is a satellite system for mobile comunications and, as such, may not be allowed to be used for fixed satellite service such as UNAVCOM II. Technically, the system is a viable and feasible approach but there are regulatory matters involving Telesat Canada and TCTS with regards to permanently installed rearward links using satellite.

With the limited 4 MHz bandwidth, Transport's requirement for frequent voice communications may cause some concern to the MSAT people. This problem can be overcome somewhat by efficiently managing the spectrum usage by such techniques as Demand Assignment Multiple Access (DAMA) schemes. DAMA effectively reduces the number of dedicated voice channels required for a system. As of June 1983, DOC does not anticipate a problem in this area.

B.5 Fixed Satellite Service (4/6 GHz)

B.5.1 Introduction

This section identifies those existing SCPC earth terminals in the 4/6 GHz range that are presently being manufactured and ways of applying prime power reduction techniqes. The 4/6 GHz satellite service has immediately two of the objectives outlined in section 3.1.1 such as availability and suitability. The satellite rearward link can be designed with power reduction techniques as described in detail below. One drawback to the system is that the rental of the earth stations and the satellite transponder is expensive and is a recurring expense.

B.5.2 Availability

There are in Canada several companies that manufacture Single Channel per Carrier (SCPC) earth stations for remote applications (see appendix). These companies are SPAR in Montreal, DTL in Mississauga, Raytheon Canada in Waterloo and SED Systems in Saskatoon. The remote SCPC terminals have been designed with ease of transportability and assembly time with little concern to prime power requirements. Although there are several different manufacturers, the basic design of the earth terminal is similar so that any power reduction techniques would be applicable to all terminals.

B.5.3 Suitability

The SCPC 4/6 GHz satellite service has been in existence in Canada since 1973. The advantage of using 4/6 GHz satellite service is that all geographical locations in Canada, with the exception perhaps of the extreme northern Artic, can access the satellite. This provides communication between any points in Canada serviced by earth terminals.

B.5.4 Power Reduction Techiques

Typically, existing earth terminals require the prime power as shown in Table 1.

Manufacturers	Prime Power Required
SPAR	300 W
DTL	300 W
Raytheon	300 W
SED	200 W

Table 1

As mentioned previously, the design of the terminals is basically the same and, therefore, DTL was used as a typical station. The power budget for a typical station is shown in Table 2 with Figure 1 illustrating a block diagram of a terminal. These breakdowns of the power budget are actual values measured by DTL.

Equipment	Power Consumption
Channel Unit	56 watts
Low Noise Amplifier	3 watts
L Band Source	8 watts
RF Oscillators	9 watts
Referecne Oscillators	8 watts
Dual U/C	8 watts
D/C	3 watts
RF Power Amp	90 watts
TOTAL	185 watts

Table 2
Power Budget for
SCPC Terminal

The above measured values were derived from equipment measured individually using lab power supplies at the required DC voltage, i.e. 12 volts, 24 volts and 5 volts.

These voltages would not be available at a site but would come from conveters and regulators. Therefore, an efficiency factor must be scaled into the values. For a switched mode power supply efficiencies of 65% and better are available. Using 65% as worst case and then incorporating this factor means a prime power requirement of 284 Watts. The wattage numbers that are used in this report will not take into account the efficiency factor.

The existing terminals were designed with ease of transportability in mind. In Figure 1, the antenna size is as small as possible, the interfacility link (IFL) which connects the the radio module to the antenna is coaxial for flexibility and ease of installation (again for transportability). These two factors require that a higher power amplifier be used with the terminal. A smaller antenna, 3.6 metres, means a smaller gain while a coaxial line means a higher loss. If the stations are to be permanently installed then a larger antenna, 4.5 metres, could be used and the IFL changed to waveguide. This would give a net gain of 3.7 dB. The RF power amplifier could then be reduced from 5 watts to 2 watts. A 2 watt RF power amplifier requires only 36 watts prime power. This would reduce the prime power requirements to 131 watts.

The next obvious power reduction would be to turn off the RF pwoer amplifier when not in use. This would reduce the requirements to 95 watts.

In examining other methods of prime power reduction techniques it is important to realize that certain pieces of equipment cannot be turned off. For example the oscillators (25 watts) cannot be turned off. They require a minimum of 10 to 15 minutes warmup time in order to stabilize the frequency.

If they are used right after turnon, the frequency would be such that the final upconverted voice carrier would have its frequency shifted and could possibley interfere with adjacent SCPC carrier as well as be outside the lockup range of the receiver demodulator.

One problem associated with SCPC systems is that the long term frequency stability of the transmitting station, satellite transponder and receive station changes with time. In order to correct in part for this frequency drift, a pilot carrier is transmitted from a central station, the receive station equipment locks up to this pilot reference and corrects for part of the long term frequency drift.

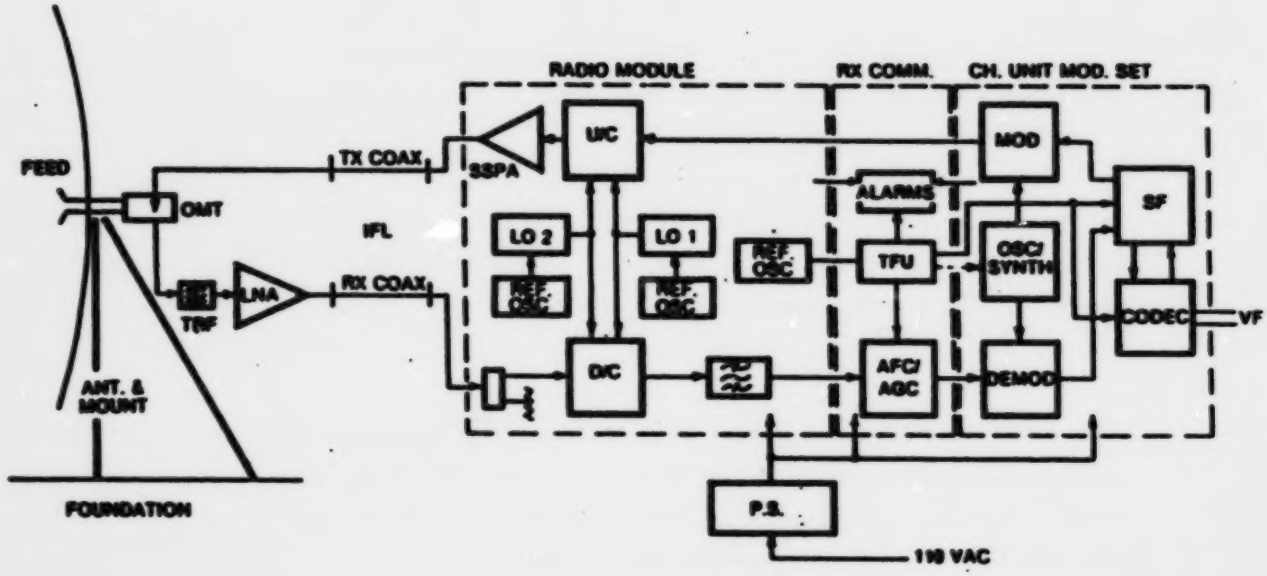


FIGURE 1

TRANSPORTABLE TERMINAL
BLOCK DIAGRAM

The pilot reference equipment requires a certain lockup and settling time after the application of DC, which might prove to be disconcerting to the aircraft pilot attempting to copy the information. These times, although not normally known, can be measured to see whether they would be annoying.

Other equipments that should be measured for lockup and settling times from a cold unpowered start would be the modulators, demodulators and frequency synthesizers.

Other items which may be left off until communication is required would be the amplifiers in the upconverter. This would save about 8 watts. The station standby power requirements would then be 87 watts.

A proposed earth station design is shown in Figure 2.0. Basically, the operation is as follows. When a pilot request originates via VHF, a voice detection circuit informs the microprocessor ON/OFF controller which would turn on the switches that power the HPA and U/C. The microprocessor controller would be part of the same unit as proposed in section 3.7.

The delay circuit of 20 - 30 ms allow for a settling time and then the pilot can communicate to the Area Control Centre. The station would remain "powered up" until a time-out circuit turns off the prime power. This time-out circuit would be adjustable.

Also, the monitor and alarm circuits prime power associated with the earth station only, could be turned off, except for say once an hour. At this time the controller would turn on power to the alarm and monitor circuits, initiate a check for alarms, and if any alarms are present, instruct the controller to turn on the rest of the transmit chain. Of course, the monitor circuits would be turned on when there was any voice data as well.

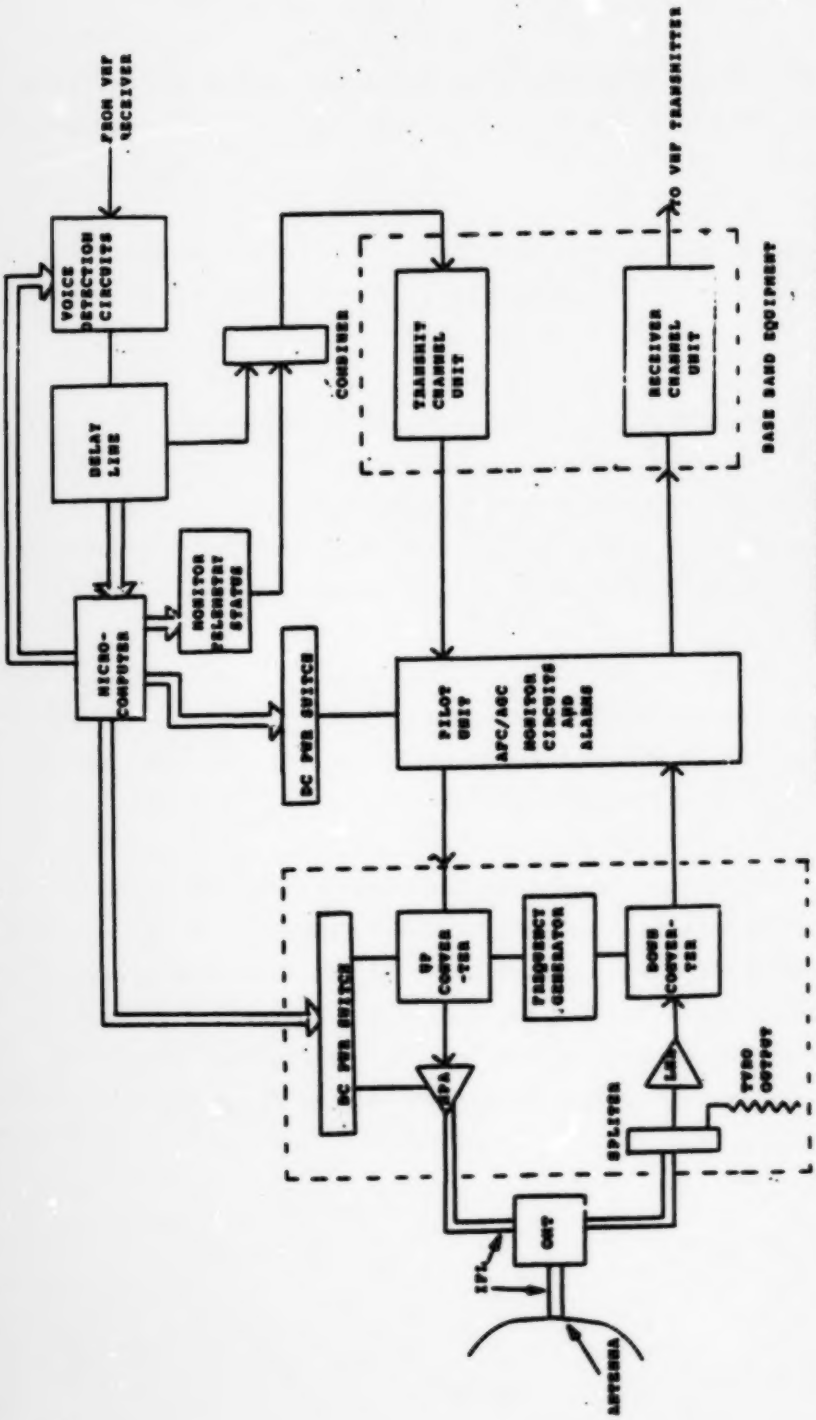


FIGURE 2 SIMPLIFIED BLOCK DIAGRAM PROPOSED REARWARD LINK WITH POWER REDUCTION TECHNIQUES.

B.5.5 Cost Effective

The only organization that can be licensed to own and operate telephony earth terminals at 4/6 GHz is Telesat Canada. The cost of for a SCPC system is in the area of $60 -70 K per year plus installation and maintenance. This would not include any terrestrial back haul that may also be necessary.

Typical prices of the existing as is SCPC terminals from manufacturers is around $50 - 55 K. Any testing and modifications would be extra.

B.6 Fixed Satellite Service 12/14 GHz

B.6.1 Introduction

With the launch of the Anik C satellite, Canada now has a commercial satellite system operating in the 12/14 GHz frequencies.

Previously, the higher frequency was used by DOC in a more experimental mode (Hermes, Anik B).

B.6.2 Availability and Suitability

The satellite exists but has one major drawback. The satellite transmit footprint was designed to cover the southern regions of Canada and consequently, does not cover the far north (see Figure 3.0).

Figure 3(a) Anik C 14 GHz Receive Pattern (G/T) (Typical)

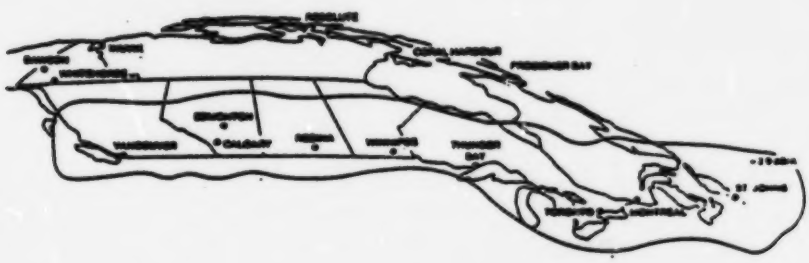


Figure 3(b) Anik C 12 GHz Transmit Pattern (EIRP) (Typical)

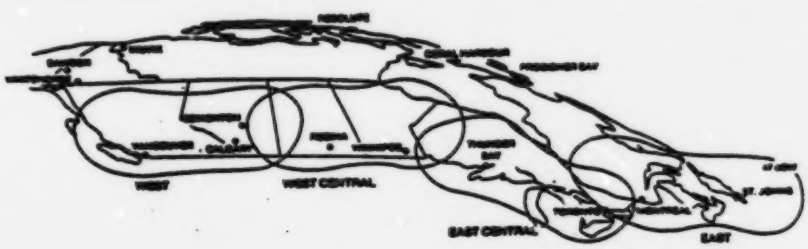


FIGURE 3.0
Typical Anik C Coverage Patterns

Telesat has "hinted" not officially, that the satellite may be tilted north if the traffic warrants. This would enable the far north to be covered but with larger antennas. This "tilting" of the satellite was proposed in 1981 when Telesat wanted to use Anik C as an interim TV direct broadcast satellite. To date, there does not exist the network system infrastructure for SCPC telephony at 12/14 GHz as it does with the 4/6 GHz system.

The Anik C system was based on very high speed digital traffic (100 M BITS/sec.) between large cities and the SCPC earth terminals are basically a result of DOC's experimental programs.

The manufacturers of 12/14 GHz terminals in Canada are AEL Microtel, SPAR and Mitel (see appendix). However, all of these companies have only produced prototype terminals to date. Although AEL have sold 25 terminals to their parent company BC Telephone for delivery in the next year.

B.6.3 Prime Power Reduction Techniques

The 12/14 GHz earth terminal design is again based upon ease of transportability and installation, as in the 4/6 GHz system. Also, many of the building blocks are identical. Therefore, the comments and prime power reduction techniques of section 3.5.4 are directly applicable.

B.6.4 Cost Effectiveness

With the Anik C system, a customer can approach the common carriers for leasing of the earth terminals. The common carriers are allowed to own and operate the earth terminals in the Anik C system, while Telesat owns and operates the satellite. However, there does not appear to be much cost savings over a 4/6 GHz system.

Typical lease costs are comparable in both systems and the cost of the earth terminal is similar.

APPENDIX C

PRELIMINARY DESIGN OF A TALK-BACK SECONDARY SURVEILLENCE RADAR FOR UNAVCOM II USE

REPORT PREPARED BY CAL'S
MICROWAVE GROUP UNDER
INTERNAL SUBCONTRACT

C.1 INTRODUCTION

The adaptation of a simple Secondary Surveillance Radar (SSR), in UNAVCOM-II, as a Talkback unit (TSSR) is quite feasible and highly recommended.

The main justification to support such a claim is the fact that this type of SSR is intended to be installed in the remote, unmanned, and very quiet air traffic zones. Thus a lot of the expensive and power hungry features of a typical SSR, of a busy airport, i.e., the plot extractors, display processors, PPI's, operator controls, and interference rejection equipment can be eliminated. The remaining radar would be, therefore, low cost and low power consumption as is so desired for UNAVCOM.

Two approaches makes the application of SSR in the UNAVCOM project feasible:

1) To purchase a suitable commercially available SSR (or some proper subsystem of it) and design an interface to connect it to the Talkback unit discussed in Section 6.

2) To develop a simplified, down to the bone, SSR which is merely proper to be used in the remote talkback mode. Such a unit can be designed around an optimized selection of off-the-shelf radar components and some in-house designed circuits. Canadian Astronautics Limited has already the necessary expertise and is well equipped to develop this version of TSSR as a separate contract.

Both of the above approaches, will be analyzed in terms of cost and power consumption, after a description of TSSR operation from pilot's point of view.

C.2 PILOT'S VIEW OF A TSSR

An aircraft flying, within the range of the TSSR, can ask for service by pressing the Special Identification (SPI) switch. The TSSR upon detecting this aircraft, with mode 3A being integrated, would receive the transponder response and would report the aircraft I.D. and location to the pilot on the aircraft VHF radio. The sequence of the events is as follows:

- pilot activates SPI switch on the transponder,
- TSSR replies, by synthesized voice, on the VHF radio:
  "AIRCRAFT SQUAWKING CODE
  ONE TWO THREE FOUR
  YOUR POSITION IS
  RADIAL ONE FIVE ZERO DEGREES
  AT ZERO FIVE MILES FROM CARP"

The pilot should deactivate the SPI switch after this, otherwise the report would be reported again and again every 30 seconds.

In the case of more than one aircraft in the TSSR range only the aircraft depressing the SPI switch would be serviced. However, if more than one aircraft is activating the SPI switch, the reports on I.D., azimuth, and range of all such aircrafts would be transmitted. Under this condition, each pilot should perceive and sort out his position as it is followed by his own aircraft I.D.

In the case of any trouble in the radar detection or any fault detection in the system, the TSSR would report:

"THIS IS CARP STATION
THE TSSR UNIT NOT FUNCTIONAL.
RELY ON NDB ONLY".

C.3 A TYPICAL SSR INSTALLATION

A typical SSR system used in an attended busy airport operation is block diagrammed in Figure 1. This system features the main/standby radar redundancy as monitored by the automatic control and changeover subsystem. The outputs of the two radars are switched to antennas or dummy loads (if hot standby is used). By the same token, the responses out of the receivers are selected from the main radar, and sent to the plot extractor unit, at the air-traffic control room, which prepares the information for display on the PPIs.

Also, operator panels to select modes of interrogations (or interlaced programs of modes) and operator interfaces to track a particular aircaraft are used in both radar site and the air traffic control room.

This radar is able to interrogate six modes, 1, 2, 3A, B, C, and D in several different sequences.

Further, this SSR is capable of operating both independently or in synchronism with a primary radar, which works on the basis of the aircraft reflection of the transmitted beam.

C.3.1 SIMPLIFIED SSR FOR UNAVCOM

The following features of the general SSR system of Figure 1 can be eliminated to taylor the system as an economic, low power TSSR for UNAVCOM operation.

1) Main/standby redundancy.
2) Changeover control unit.
3) Local and remote operator programming panels and related electronics.

4) Multi-mode interlacing features, only mode 3A would be interegated.
5) Primary radar synchronization circuit, since independant SSR operation is needed only.
6) Plot extractor processor unit which is the most expensive and power consuming part of an SSR.
7) Display processor and PPI units.
8) Aircraft selection and tracking features.
9) Data communication and video driving units between the radar site, in the field, and the control room.
10) The cabling or communication medium for the above link.
11) Defruiter and interference rejection equipment, which are normally used by busy airporst.

What remains to be used is conceptually shown in Figure 2. It consists only of the components necessary to extract the aircraft response code and feed it to the Talkback interface unit.

The following two approaches, to achieve such an SSR, are discussed in Section 4 and 5:

- Using a commercially available SSR.
- A custom SSR designed for the UNAVCOM.

C.4 USING A COMMERCIALLY AVAILABLE SSR FOR UNAVCOM

In this approach a suitable commercially available SSR (or proper subsystem of it) is purchased and an interface is designed to extract the aircraft I.D., range and azimuth angle and feed them to the talkback unit.

VLATME (Very Light Air Traffic Management Equipment) Radar from AIL Division of Eaton's Corporation is the best candid for such a purpose. This radar weighs about 150 lbs., uses about 285 watts power and costs approximately $300,000.

A version of this radar, Model AN/MSQ-117, is shown in Figure 3a, with the specification given in Table 1.

This radar features the following:

1) Modular construction with each functional unit as a separate entity. This provides us with the feasibility of purchasing only the required units without degrading the performance of the other units.

2) The radar is mounted in a standard 19" rack with some blank shelves which could be used to house our talkback unit and the related interfacing.

3) The radar contains self-test features by making check on internally generated targets. Therefore, if there is a fault, the talkback unit could be informed to report it to the service requesting aircraft.

4) The radar features defruiter and de-garbling circuits to minimize interference signals. Although these features are not very essential in a UNAVCOM style of installation.

5) The radar is capable of detecting the elevation angle which is not needed in UNAVCOM.

6) The radar is designed to be operated remotely with ASCII control inputs and BCD radar detection outputs which is so desired in UNAVCOM operation.

7) The range of the radar is 60 NM maximum. However, according to manufacturer, this can be increased either by a modification in the power amplifier or reducing the antenna scan rate. The high scan rate of the antenna (60 rpm) is proposed for busy air traffic and management of up to 100 aircraft which is not needed in UNAVCOM.

8) The radar also features a 5" crt display and an adaptive tracking feature which are not needed in UNAVCOM. These features could be eliminated to provide cost and power savings for our application.

The block diagrm of this SSR is shown in Figure 3b. This radar consists of the following:

- antenna,
- antenna control unit,
- coder/processor,
- display/processor,
- 24 volt power supply.

As seen, the target information is available from the coder processor in RS-232 serial format. This is the point to interface the radar to our talkback unit of Section 5.3.

To do this, a serial RS-232 port should be added to our talkback microcomputer. This interface is shown in Figure 3c. It consists of RS-232 buffers and a Universal Synchronous Receiver Transmitter (USRT).

The format of the target message is given in Appendix 1, and the software of the talkback computer should be modified in order to accept such a message.

The software modification is minimal since the message is sent in synchronous form with two start bytes (see Appendix 1) which could be used to generate the aircraft detection interrupt to the talkback microcomputer; Section 5.3.

Also, another port, in our talkback microcomputer system, is needed to check the SSR faults so as to forward "SSR not Functional" message to the service requesting aircraft. Although some communication fault reporting is contained in the target message, this port is necessary to report the SSR operational faults and is connected to the internal fault detection circuitry of the VLATME.

With the above interface, to the VLATME SSR, there would be no need for the "display/display processor" and it is possible to eliminate it in A UNAVCOM installation. This provides us with a major cost saving and a saving of 75 watts power in the SSR consumption. It also clears some space in the rack which could be used for other equipment.

Moreover, the possibility of operation of VLATME with 24 V dc, could provide some savings, in the power supply cost and loss, if it is possible to operate some other UNAVCOM equipments with 24 V dc.

C.5. THE CUSTOM SSR FOR THE TALKBACK OPERATION

This SSR is the basic radar shown in the block diagram of Fig. 2. It outputs the aircraft detection in the form of processed and reshaped transponder video signals to the Talkback Interface unit which in turn feeds Aircraft I.D., Range, azimuth, as well as the SSR Status to the Talkback unit.

This propsosed SSR can be developed by CAL into a product with a cost of a fraction of a commercially available one. It consists of the following components.

1. Directional omni antennae designed for L band.
2. Diplexer or circulator to make the use of antennas for both transmission and reception.
3. 1030 MHz transmitter with sufficient power to provide 100 nm SSR range.
4. Coder or Interrogate pulse generator which generates SSR interrogation pulses P_1P_3 as well as side lobe suppression pulse P_2 according to ICAO specifications.
   This coder only generates mode 3A, (since other modes are not of interest in a Talkback radar) with an adjustable PRF of 150 to 450 Hz in free running mode (No primary radar exists in UNAVCOM for synchronous operation).
5. Modulator to modulate the coder pulses to the transmitter.
6. Receiver, it is a 1090 MHz super hetrodyne receiver with STC (Sensitivity ramping control to receive near and far detections at the same levels.).
7. Video Processor, shapes the transponder pulses to the standard logic levels (say TTL). It also rejects noise or other parasitic spikes.

8. Antenna position sensor: The directional antenna rotates with a rate of 5 rpm. Its position is detected by an optical detector circuit which produces two signals as follows
   - ARP (Antenna Reference Pulse) which is a pulse generated every time the antenna beams North.
   - ACP (Antenna Change Pulse) which is a pulse generated every θ degree of antenna rotation. Where θ should be defined for the particular design.

Each of the above blocks will be described in the subsection 5-1 and will be cost and power estimated.

The information is outputted, from such an SSR, in the form of three groups of signals.

1. Antenna position ARP and ACP pulses
2. Video signal (transponder answer pulses cleaned up and shaped)
3. Interrogation (Beacon synch and P_1P_3 pulse)
4. SSR Status and fault detection

An Interface should be designed between the above-proposed SSR and the UNAVCOM Talkback unit. This interface is shown in Fig. 4. It accepts the above mentioned inputs and outputs in the following binary words to the Talkback unit.

- Aircraft I.D.
- Aircraft Range
- Aircraft Azimuth angle
- Status of detection (such as valid, SSR non-operational, etc)

The internal design of this Interface unit is block diagrammed in Fig. 5 and is described and cost-power analyzed in subsection 5.2.

Finally the Talkback Unit is basically a microcomputer system. It receives the aircraft I.D. and its position information along with the SSR Status. It performs averaging and statistical analysis on the SSR findings and forms the report message. This report message is loaded to a voice syntheszier which talks into the VHF radio transmitter.

The unit is shown in Fig. 6 and is described in detail in subsection 5.3 along with its cost and power estimates.

C.5.1 Design Analysis of CAL's Proposed SSR

The design of such a radar can be divided into digital parts, RF parts, and the antennas.

The digital parts consists of the Coder (Interrogate pulse generator), Video Processor, Fault Monitor, and Antenna position detector. Each of these units are described as follows:

C.5.1.1 Interrogate Pulse generator

This unit is basically a pulse generator which produces $P_1P_2P_3$ SSR integration pulses for mode 3A (i.e. P_1P_3 spacing of 8 μs). It also generates a trigger pulse call SSR Beacon synch, as shown along with $P_1P_2P_3$ in Figure 7.

The group repeatation rate of these pulses (PRF) is variable from 150 to 450 Hz.

The module is block diagrammed in Fig. 8. It generates the pulses by sweeping across the address range of a PROM, having $P_1P_2P_3$ stored in it. The addresses, for such a sweep, is generated by a counter driven by a crystal clock.

The module is implemented in low power shotky TTL and the estimated power consumption is less than 5 watts.

Cost estimates are:

Development cost		$12,000
Development time		200 man/hr.
Product cost	(for 30 units)	$ 1,200 each

C.5.1.2 Video Processor

The module shpaes the video pulses to TTL level and rejects any Pulse less than 250 ns.

The module is block diagrammed in Fig. 9. The shaping is based on widening the input pulse by twice delaying of 50 ns and adding the input and the most delayed pulse (100 ns delayed pulse). This widened pulse is divided by 2 and compared to the 50 ns delayed pulse. The result would be a TTL pulse with a width equal to half amplitude width of the original input pulse.

The spike rejection is accomplished by passing the shaped video pulse through a 250 ns tapped delay line and ANDing all the taps. The AND gate produces a logic 1 which lets the pulse pass through if it fills the delay line.

The module uses transistors, OP-Amps and LS-TTL circuitry. The power consumption is less than 10 watts. The cost estimates for this module are:

Development cost	≈ $18,000
Development time	≈ 350 man-hr.
Product cost (over 30)	≈ $ 1,800 each

C.5.1.3 Fault Monitoring

This circuit monitors the SSR, detects faults and reports them to the talkback interface circuit.

It is a single chip microprocessor plus some LS TTL timer/counters to measure the timings envolved.

The functions monitored are as follows:

1-Interrogation pulse width
3-Interrogation mode timing
4-Transmitter output power
5-Transmitter output VSWR
6-Receive sensitivity fault

The power consumption of the circuit is less than 8 watts and cost estimates are:

Development cost	≈ $24,000
Development time	≈ 400 man/hr.
Product Cost (spread over 30)	≈ $ 2,000 each

C.5.1.4 Antenna Position Detector

The azimuth position angle of the directional antenna is detected by an optical sensor and electronic pulser circuit. This circuit produces a TTL pulse when antenna passes the reference (Say North) called Antenna Reference Pulse, ARP. It also produces a pulse train called Atenna Change Pulse, ACP, which is one pulse per θ degree rotation of the antenna; where θ is to be defined in the design process to give the required accurracy.

The circuit uses less than 5 watts in power. Its cost estimates are:

Development Cost	≈$12,000
Development Time	≈ 200 Man-hr.
Product Cost (spread over 30)	$ 1,200

C.5.1.5 The RF Parts

The RF parts consists of the modulator, Transmitter parts, and receiver parts. The design is block-diagrammed in Fig. 10.

The transmitter part consists of a 103.0 MHz crystal ocsillator followed by a phase-lock-loop multiplier which brings the RF frequency to 1030 MHz. This RF is fed to the PIN diode modulator through a 3-way splitter and is followed by a harmonic filter and power level adjuster, high power amplifier, and another harmonic filter. The output at this point is RF modulated by $P_1P_2P_3$. It is separated to RF P_1-P_3 for directional antenna and to P_2 for the omni antenna by a high power PIN switch (SLS switch). The output of the high power switch is fed to the antennas through diplexers and directional couplers. The flow of energy to the antennas is to notify the fault circuit in case of a failure.

The receiver part consists of diplexers to separate receivor 1090 MHz RF from transmitter 1030 MHz, some preamplification stages and the mixer which mixes the transponder 1090 MHz with 1030 MHz to produce 60 MHz IF signal. The 60 MHz signal is amplified, filtered, and detected to video pulses by log amplifier/detector circuit. The use of log amplifier compresses the very wide dynamic range of the received pulses. It also simplifies the use of STC gain control because the changing of the receiver sensitivity, according to $\frac{1}{R^2}$ law, will lead to the addition of a ramp function in the log amplifier.

The detected video in the directional and omni channels are properly scaled by the "level Adjust" and compared to each other. Further processing of the video pulses will be disabled if the video from directional channel is not larger than the video from the omni channel. This is called receiver side lobe supression (RSLS) and is used to sharpen the beam of the directional antenna.

The cost and power estimates are as follows:

Component	Power Consumption	Cost (spread over 30)
Crystal Oscillator, filter	0.5 W	$ 500
PLL multiplier	8.0 W	$ 1,300
Splitter	-	$ 400
PIN modulator	1.5 W	$ 700
1030 MHz - Bandpass filters	-	$ 700
Power Divider	-	$ 200
High Power Amplifier	120.0 W	$15,000
Harmonic filters	-	$ 700
SLS High Power Switch	10.0 W	$ 1,500
Diplexer (2 units)	-	2 x $ 2,000
Dual Directional Coupler	-	2 x $ 500
Detectors	-	5 x $ 300
Receiver Preamplifiers	2 x 2.0 W	2 x $ 2,000
Mixer	-	2 x $ 600
IF circuitry (amplifier, filter, log amplifier and detector)	2 x 5.0 W	2 x $ 4,000
Beam Sharpenning Comparator & Delay	5.0 W	$ 1,800
Power Supplies	-	$ 300
Cable, Adaptor, Connectors	-	$ 2,500
Box and Enclosures	-	$ 500
Miscellaneous such as Attenuators, Couplers etc.	-	$ 2,500
Development cost per Unit (spread over 30 units)	-	$ 4,000
TOTAL PRODUCT	160.0 W	$53,000
Development time 900 man hr. Development cost $105,000		

C.5.1.6 Antennas

The directional antenna would be a broadside dipole array antenna with 12 elements, half-wave length apart from each other, as shown in Fig. 11. The approximate characterists are as follows:

Gain	≈ 50
Elevation beamwidth	≈ 55°
Azimuth beamwidth	≈ 11°

The size is 180 cm X 40 cm and is rotated 5 rpm by a motor gear mechanism which is oiled and sealed to work for a long time without maintenance.

The cost and power budget is as follows:

Antenna and rotofeeder	$5,000
Rotation mechanism	$3,000
Power consumed by rotation mechanism	15 W

The antenna would be installed on a pedestal about 3-4 meters high on top of the TSSR shack.

The omni antenna is dipole antenna installed on the top part of the shack as well. The cost is approximately $2,000 with the feeder.

C.5.1.7 Total Cost and Power Estimates for the Proposed SSR

Adding all the figures determined in the previous subsections of Section 5.1, the toal estimates for the custom SSR proposed, spreading the development costs over 30 units, is as follows:

Submit	Power Consumption	Product Cost
Coder	5 W	$ 1,200
Video Processor	10 W	$ 1,800
Fault Monitoring	5 W	$ 2,000
Antenna Position Detector	5 W	$ 1,200
RF Parts	160 W	$53,000
Antennas	-	$ 7,000
Antenna Rotation Mechanism	15 W	$ 3,000
Atenna Pedestal	-	$ 2,000
Rack and Packaging	-	$ 2,600
Power Supply		$ 500
TOTAL	200 W	$72,300

C.5.2 Design Analysis of Interface Unit

The Interface unit of Fig. 4 is further detailed in design in the block diagram of Fig. 5.

It consists of the following:

C.5.2.1 A Frame Decoder

It detects the arrival of F_1F_2 pulses by delaying F_1 and ANDing it with F_2.

C.5.2.2 SPI Pulse Detector

This decoder detects whether the SPI pulse is inserted into the transponder response or not. If so, it means that the aircraft is asking for service and it triggers the report in the talkback unit. It is implemented by a low power shottky TTL timing circuit.

C.5.2.3 Aircraft I.D. Decoder

The Aircraft I.D. Decoder identifies the aircraft I.D. code, which is formed by the transponder as pulses inserted between F_1 and F_2. It is a shift register plus a code convertor PROM.

C.5.2.4 Range Decoder

The Range Decoder is a TTL timer/counter circuitry which measures the time from the interrogation (P_3 pulse) to the detected response (the detection of F_1F_2). It outputs this time in parrallel form to the Talkback unit.

C.5.2.5 Azimuth Decoder

The Azimuth Decoder is basically a TTL counter circuit which counts the number of ACP pulses generated after ARP, thus indicates the antenna position with respect to North. The result is reported to the talkback unit.

C.5.2.6 Supervisory Logic

This circuit generates an interrupt to the talkback microcomputer, upon completion of I.D., Range and azimuth decoding in the related circuits. The interrupt causes the target information to be read by the talkback unit only if there is no fault reported by the SSR, otherwise the fault report is read by the talkback unit which results in reporting: "SSR is not functional.".

After the I.D., range and the azimuth decoders are read by the talkback unit these circuits are cleared and reset by the supervisory logic.

The circuit is implemented by logic elements such as gates, latches, and one shots.

The power and cost estimates for the Interface Unit are as follows:

Circuit	Power	Product Cost (over 30)
Frame Decoder	4 W	$ 800
SPI Detector	2 W	$ 500
I.D. Decoder	3 W	$ 800
Range Decoder	2 W	$ 700
Azimuth decoder	2 W	$ 500
Supervisory Logic	2 W	$ 800
Packaging	-	$ 200
Engineering & Development Cost Per Unit (over 30 units)	-	$2,000
TOTAL	15 W	$6,300

C.5.3 The Talkback Unit

The talkback unit receives the I.D., Range, Azimuth, and status information from the SSR and reports them, back to the aircraft, by the aircraft VHF radio. It also logs these communications, along with the date and the time of the day, digitally or on a tape recorder. The recording can be played back manually or remotely from a manned ATC station via sattelite remote and telemetry.

The unit basically is a microcomputer with peripherals controlling a voice synthesizer, the VHF radios, and the tape recorder. The unit is block diagrammed in Fig 6 and the operation is as follows:

The SSR output information are read from ports 1, 2 and 3 under status/handshaking controls of part 4. They are statistically processed, averaged, and prepared in the form of addresses of vocabularies of the voice synthesizer. Also, the radios (and the tape recorder) are switched ON for the period of the reporting.

A digital real time calender/clock and a hardwired timer is connected to the microprocessor. The real time clock feeds the date and the time for the logging purpose. The hardwired time generates an interrupt to the processor for repeating the report, once every 30 seconds, as long as the aircraft keeps the SPI switch ON.

The control program is flow charted in Fig. 6b. It consist of the following:

1) Interrupt routine which is called upon by SSR interrupt from the SSR interface when an aircraft is detected. It flags the detection status and sorts the valid reading from the invalid ones (by comparing the reading to a running average of the previous readings) and updates the report running average, Fig. 6b.

2) Hardwired timer interupt routine; which is called by time counter every 30 seconds, if enabled by the main program. It controls the radios and logging recorder and feeds the voice synthesizer with the report message; Fig. 6b.

3) The main program, which coordinates the aircraft detection and the reporting by enabling or disabling of the hardwire timer interupt.

   It also averages the result and forms the report message in the report buffer so as to be ready for hardwire timer to be fed to voice synthesizer; Fig. 6c.

The microprocessor used would be a popular 8 bit one, such as 8085 or Z80. The anticipated memory size will be about 4 to 8 K bytes for program memory (EPROM), about 2 K byte for the RAM. The voice synthesizer would be National Digitalker*™ with a custom ordered vocabulary PROM.

The voice synthesizer receives the message from the microprocessor, word by word, in the form of vocabulary addresses, from port 6, and outputs them in the form of audio signal to microphone inputs of the radios as well as to the tape recorder. Port 7 controls the ON/OFF switching of the voice synthesizer, radios, and the tape recorder. Also, port 7 monitors the operation of these devices.

The tape recorder is used for the purpose of logging the traffic and the TSSR reports. For this purpose an alternative would be to store the reports in the RAM, in the form of word addresses, at the time of being outputted to the voice synthesizer. These reports could be collected for a predefined period of time, say a day or a week. They can be played back by sending them back into the voice synthesiser upon request of the Remote/Telemetry subsystem while the output of the voice synthesizer is switched to UHF rearward satellite radios instead of VHF talkback radios, Fig. 6d.

Such an approach requires a much larger size of RAM in the microcomputer, depending on the extent of the logging period. Also, the logged reports are volatile; i.e. they would be destroyed upon a power interruption of the microcomputer. The availability of a documented tape is not possible either. However, the approach provides some reliability due to elimination of a mechanical tape recorder.

Cost and Power Estimates

The cost and power consumption of the subunits used in the talkback unit, Fig. 6, is as follows:

Submit	Power Consumption	Cost
1-microprocessor, memory,ports hardwired timer, and bus support	13 W	$ 1,400
2-Real time calender/clock	2 W	$ 300
3-Voice synthesizer	3 W	$ 400
4-Custom vocabulary PROM	2 W	$ 300
5-VHf radios and antennas	28 W	$ 4,000
6-Radio controller logic	2 W	$ 300
7-Tape recorder or its RAM equivalent	5 W	$ 200
8-Packaging and Hardware		$ 500
9-Engineering & programming development cost spread over 30 units		$ 3,000
TOTAL	55 W	$10,500 /unit

Conclusion

The feasibility of using a Secondary Survillance Radar (SSR), in a Talkback mode, was studied for UNAVCOM station. It is found that such an implementation is highly recommended and prefered, as compared to using a Doppler Direction Finder.

Two approaches for such an implementation are considered, namely:

1) Purchasing a commercial SSR and interfacing it to the Talkback unit.

2) Developing a simple, dedicated SSR for talkback mode, and using it with the talkback unit.

Both approaches are described in detail in sections 4 and 5. The two approaches are compared in cost and power consumption, as follows:

Approach 1: Using VLATME Radar

UNIT	POWER	COST
SSR (Subsystem)*	250 W	$250,000
Talkback unit	55 W	$ 10,500
Interface	15 W	$ 5,000
TOTAL	320 Watts	$265,500

Approach 2: Using Proposed Custom SSR

UNIT	POWER	COST
SSR	200 W	$ 72,300
Talkback unit	55 W	$ 10,500
Interface unit	15 W	$ 6,300
TOTAL	270 W	$ 89,100

* Assuming some of the features are eliminated.

As seen, the power and cost in approach 1 are higher by a factor of about 3. This, of course, is the price paid for a radar having been designed for the control of a busy Military tactical traffic, which is able to manage up to 100 aircrafts and having all the features of a full SSR system. Most of these features are not needed in UNAVCOM and unfortunately not all of them can be eliminated, for savings, without affecting the total system performance.

The development cost of the custom SSR by CAL is as follows:

For RF Parts	$105,000
For digital part	$ 66,000
For Antennas	$ 30,000
unpredicated expenses	$ 50,000
Total	$251,000

Adding the development cost for the talkback unit ($90,000) and the interface unit ($60,000) and $10,000 for the system integration, the total development cost of TSSR is

251,000
90,000
60,000
10,000
$411,000

However, as a product the total TSSR would cost $89,100 each for 30 systems; or $75,400 each if development cost is paid as a separate contract (for 30 units).

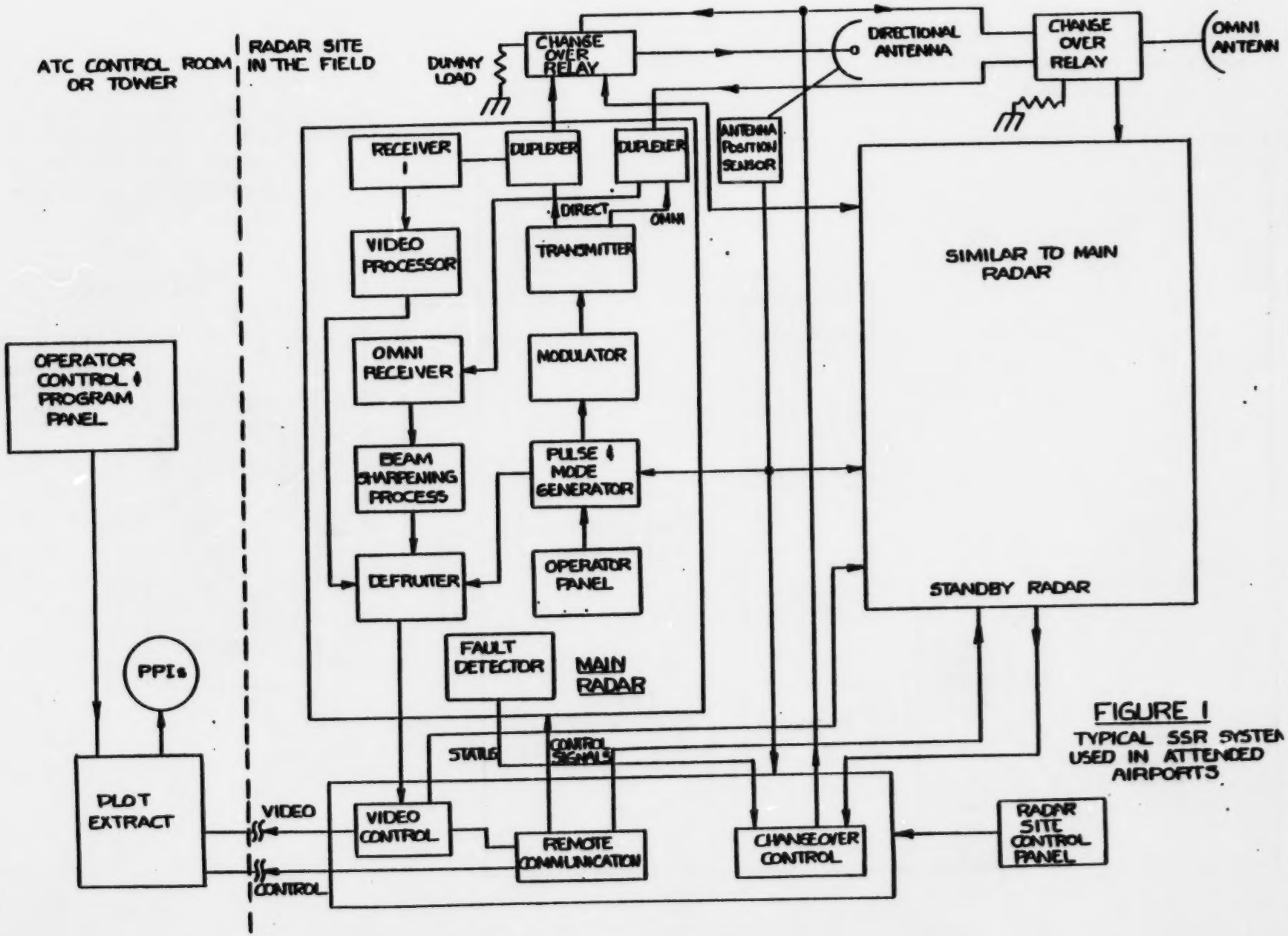


FIGURE 1
TYPICAL SSR SYSTEM USED IN ATTENDED AIRPORTS

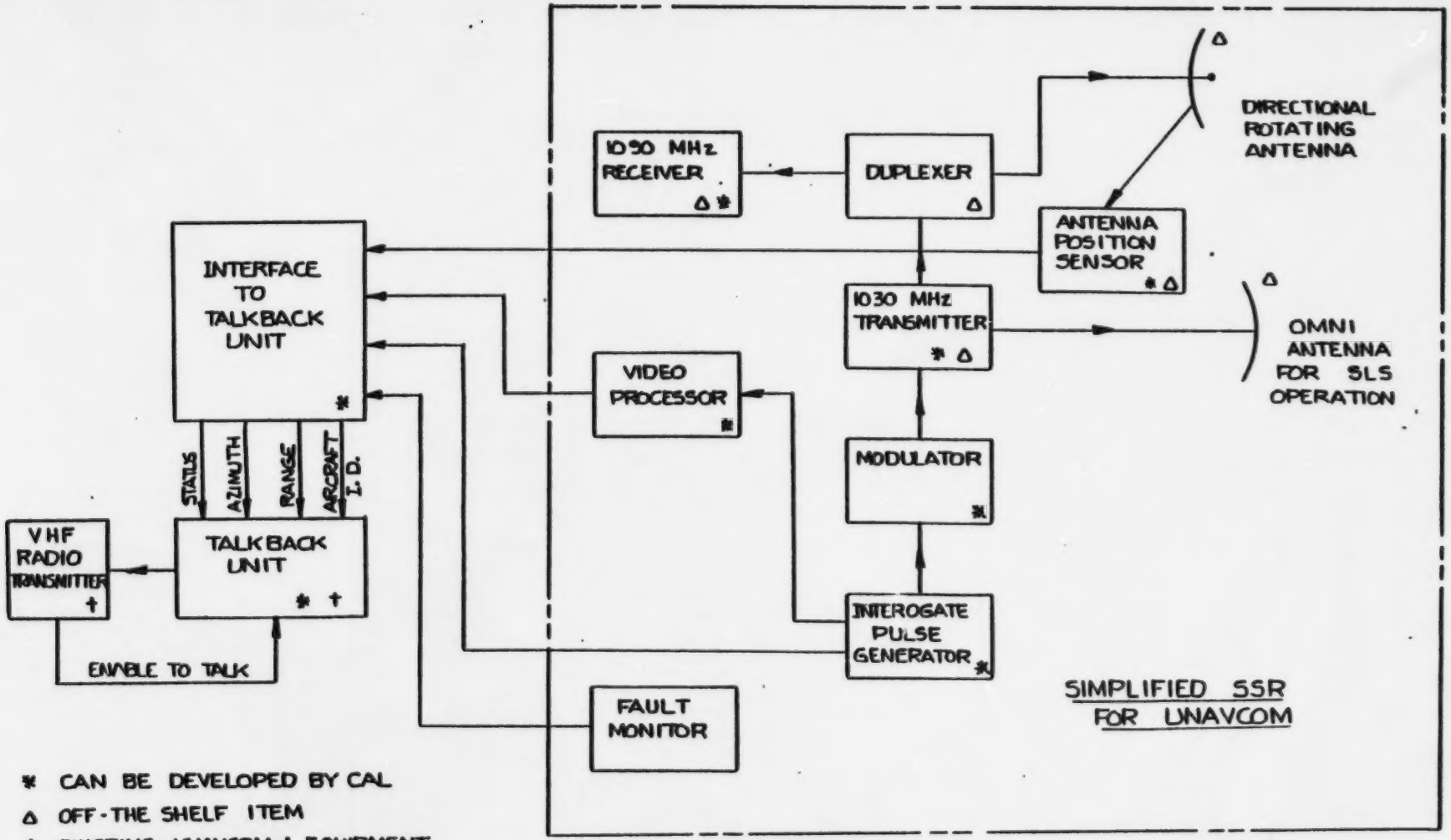


FIGURE 2
SYSTEM DIAGRAM OF TSSR

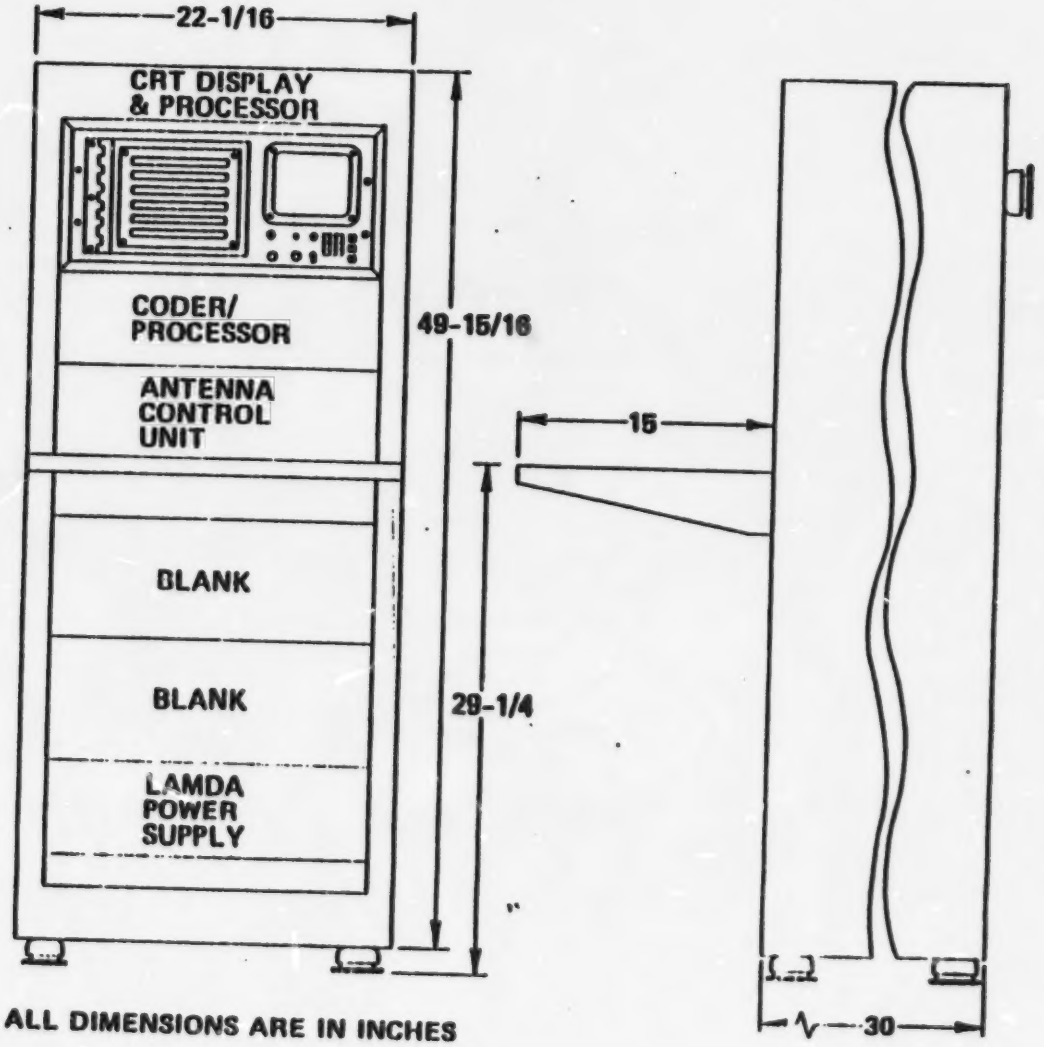
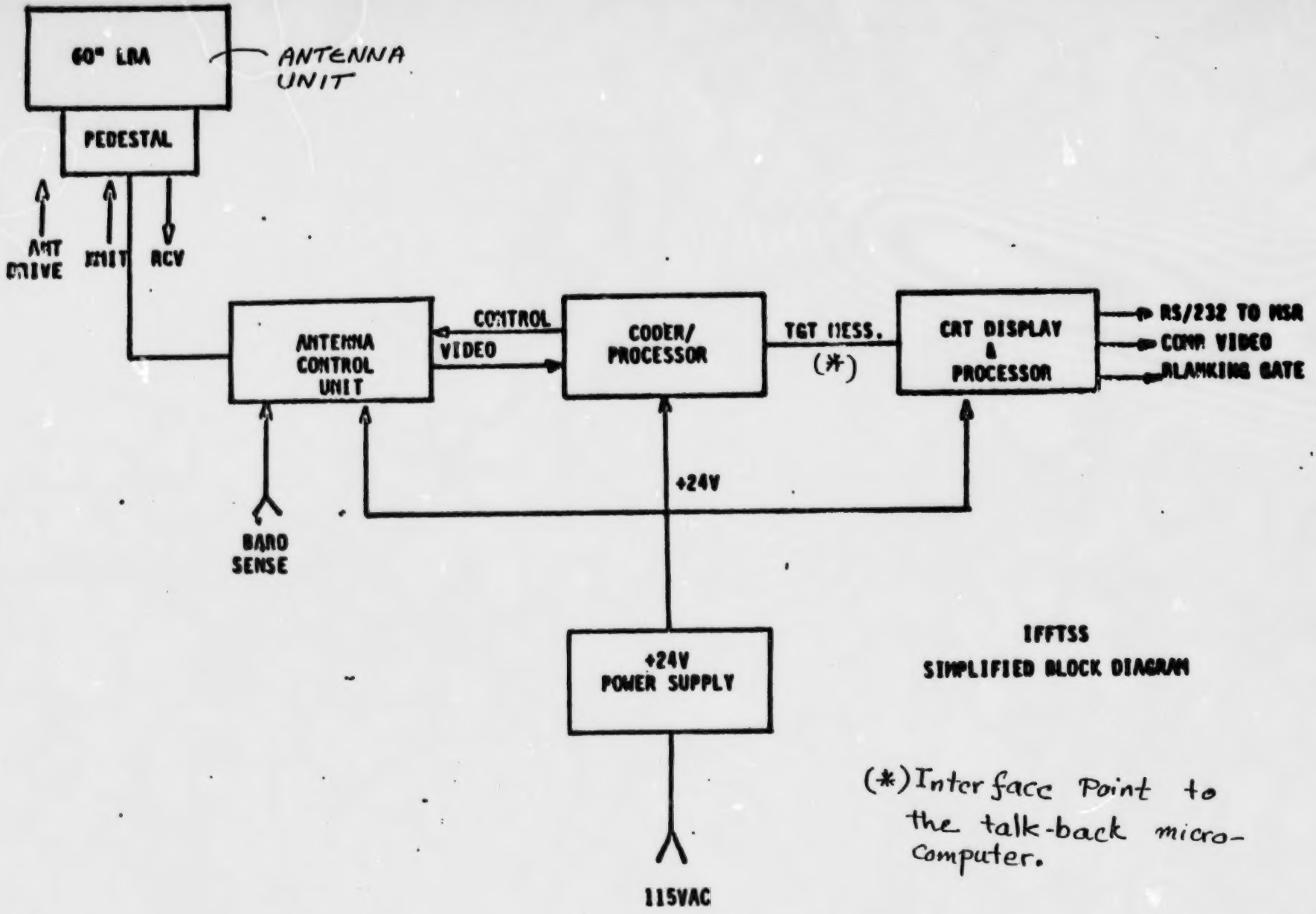


FIGURE 3a VLTME RADAR



IFFTSS
SIMPLIFIED BLOCK DIAGRAM

(*) Interface Point to the talk-back micro-computer.

FIGURE 3b BLOCK DIAGRAM OF VLATME

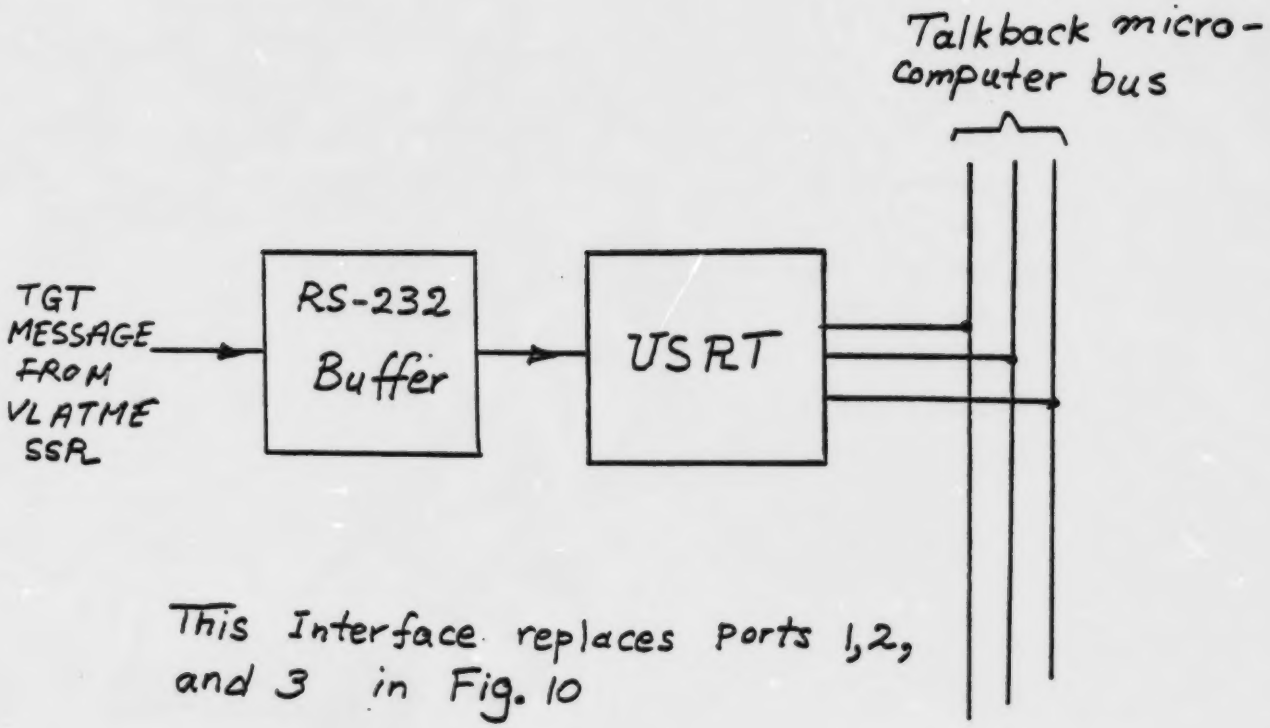

Talkback micro-computer bus
TGT MESSAGE FROM VLATME SSR
RS-232 Buffer
USRT
This Interface replaces ports 1, 2, and 3 in Fig. 10

FIG 3C : INTERFACE BETWEEN VLATME SSR and TALKBACK UNIT

TABLE 1

VLATME RADARS

AN/MSQ-117, SPECIFICATIONS

Antenna Scan Rate	-	60 RPM
Interrogation Frequency	-	1030 MHz
Interrogation Power	-	1000 Watts
Interrogation Modes	-	1,2,3A, C
Interlace	-	One, two, or three modes
Receive Frequency	-	1090 MHz
Receiver Threshold	-	-84 dbm
Display	-	5 inch (diagonal) CRT
Display Range	-	10,30 or 60 Nautical Miles
Acquisition Envelope		
Slant Range	-	1.0 to 60.0 Nautical Miles
Azimuth	-	360° continuous
Elevation	-	-5 to + 80 degrees
Azimuth Accuracy	-	± 0.5 degrees RMS
Elevation Accuracy	-	± 0.5 degrees, ranges 2.0 Nautical Miles minimum
Range Accuracy	-	± 100 yards
Power Drain	-	Approximately 285 watts at 24 volts

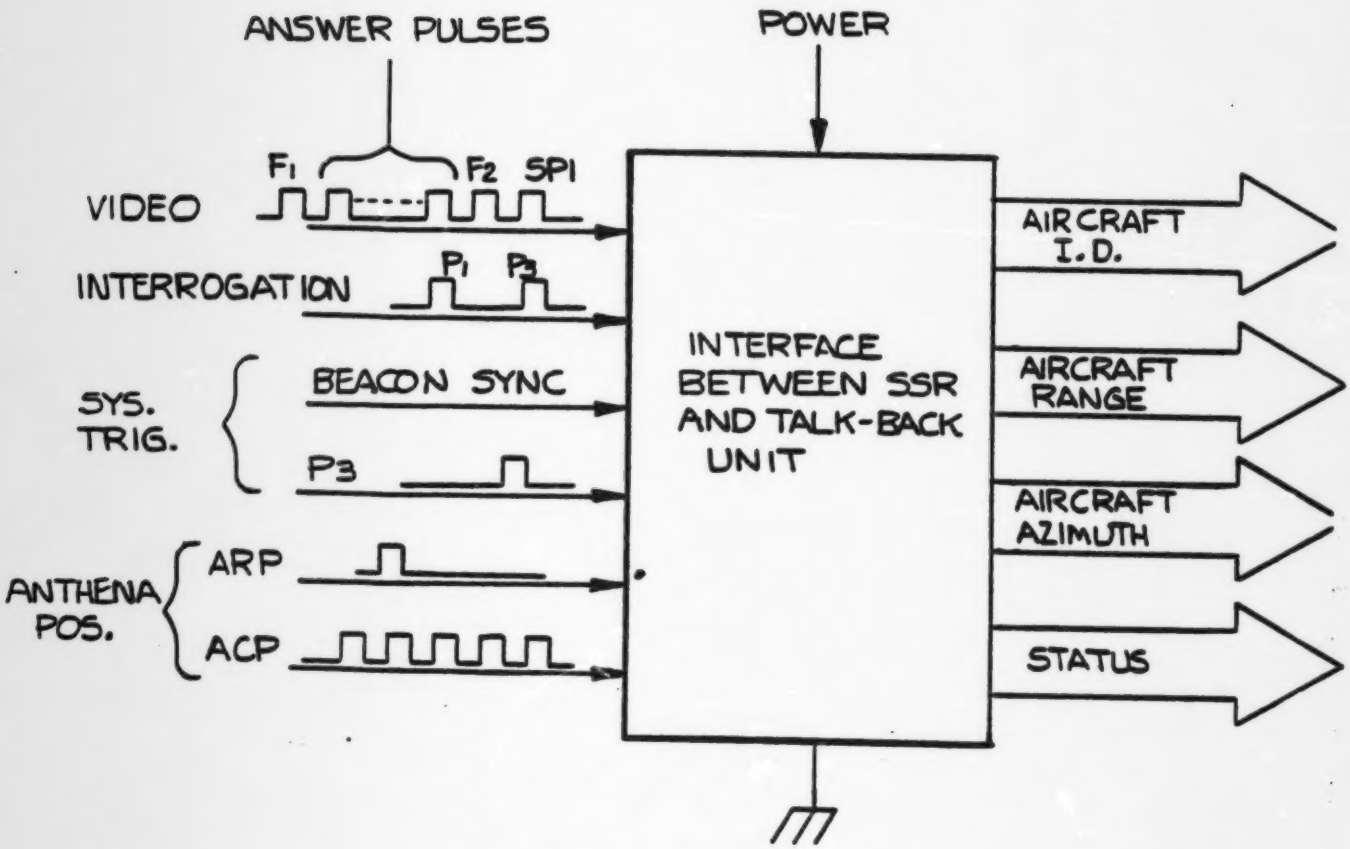


FIG. 4 INTERFACE BETWEEN CAL'S PROPOSED SSR AND TALKBACK UNIT

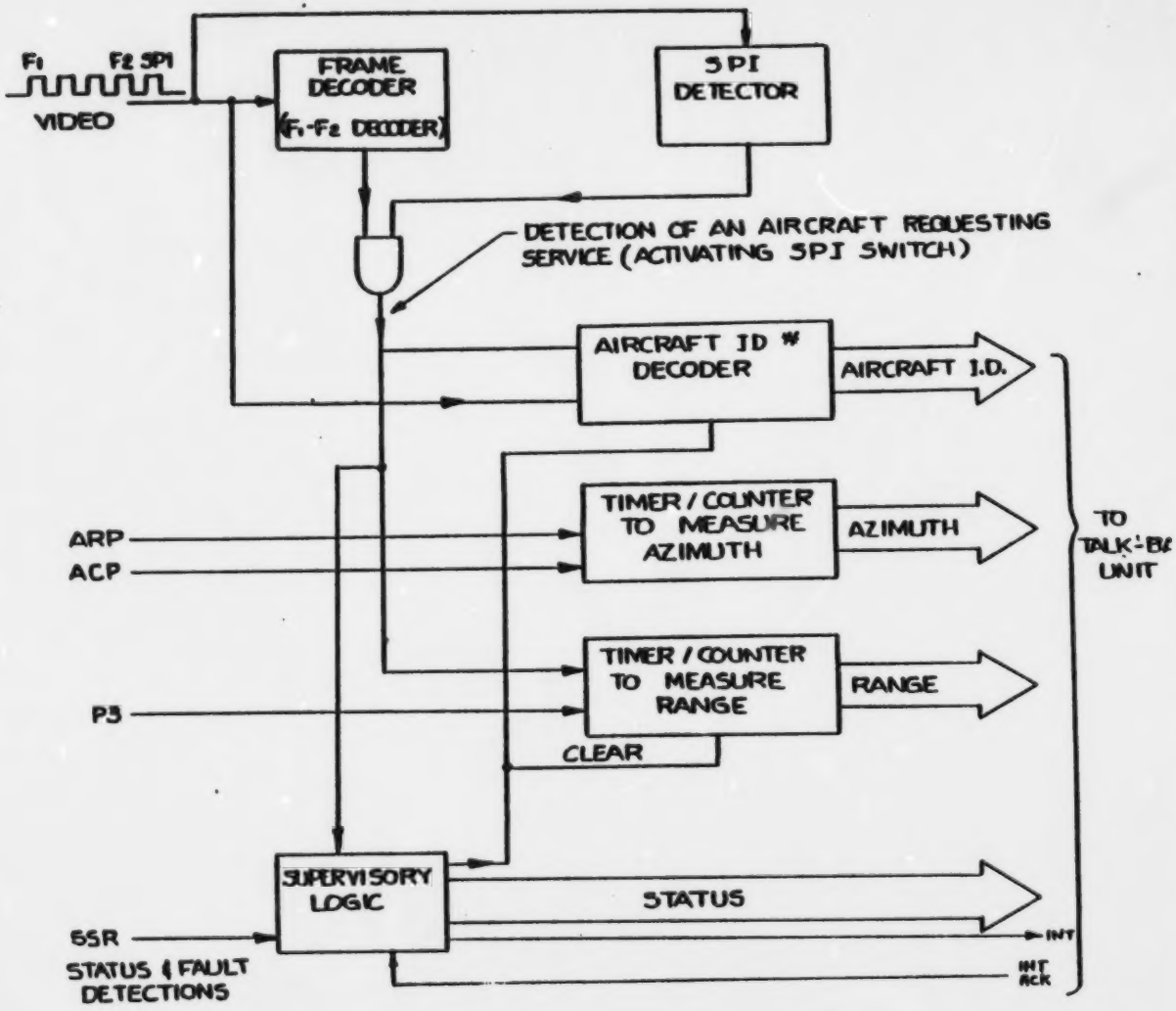


FIGURE 5 INTERNAL STRUCTURE OF THE INTERFACE BETWEEN SSR & TALKBACK

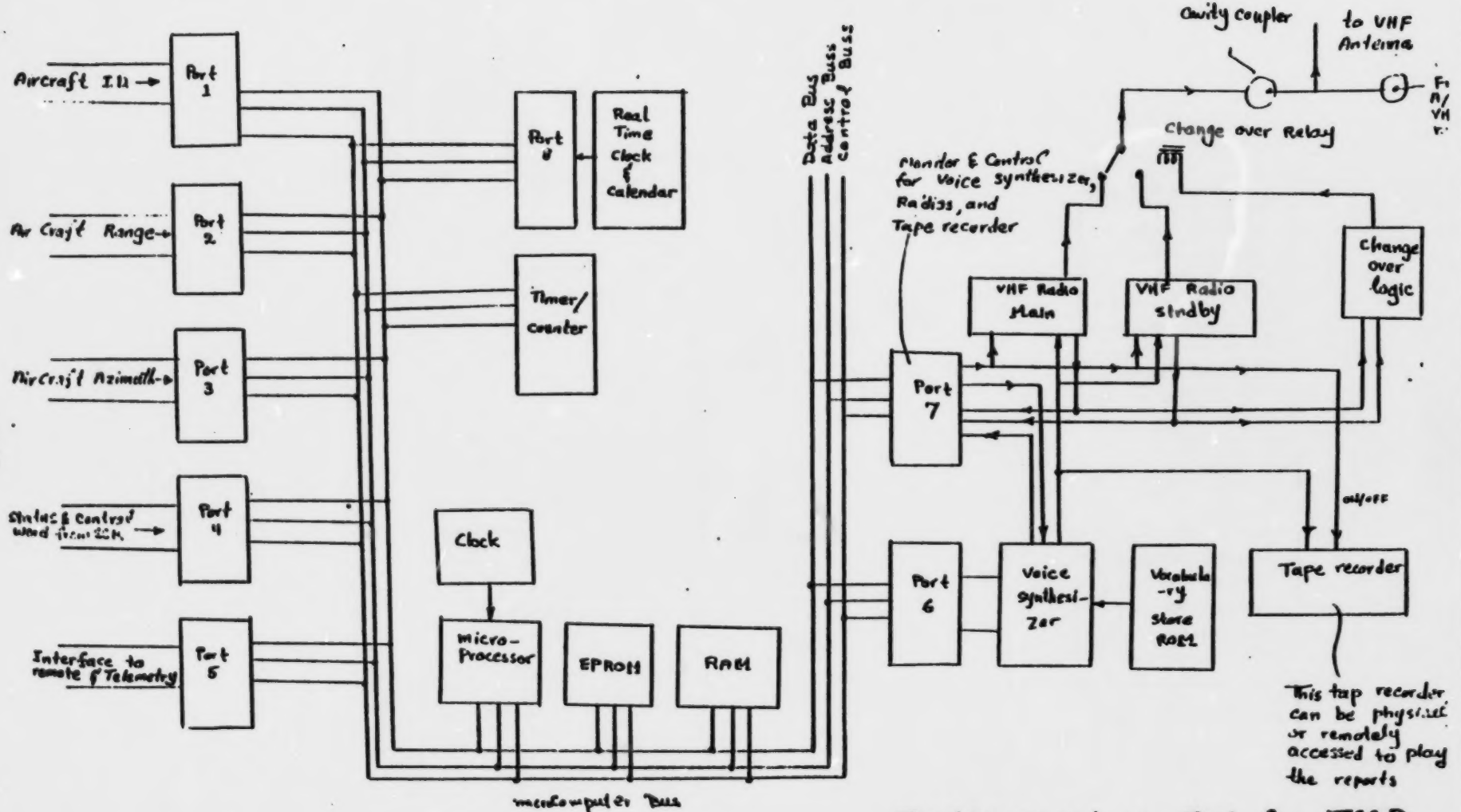


Fig.6a: Talk back Unit for TSSR

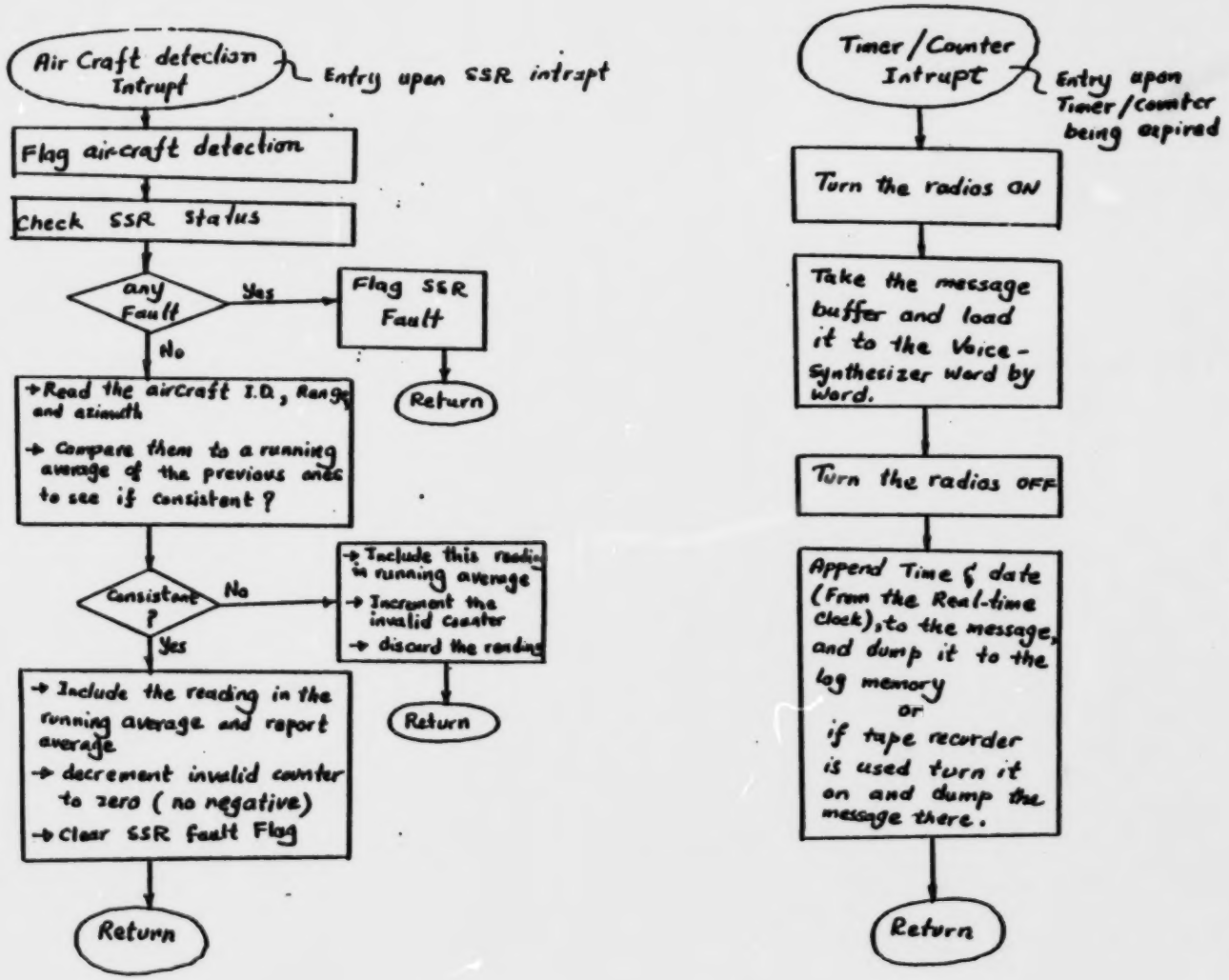
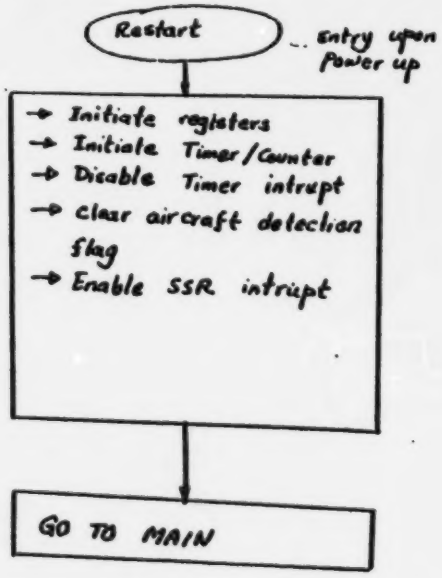

Air Craft detection Intrupt
Entry upon SSR intrupt
Flag air-craft detection
Check SSR status
any Fault
Yes
Flag SSR Fault
Return
No
→ Read the aircraft I.D., Range and azimuth
→ Compare them to a running average of the previous ones to see if consistent ?
Consistent ?
No
→ Include this reading in running average
→ Increment the invalid counter
→ discard the reading
Return
Yes
→ Include the reading in the running average and report average
→ decrement invalid counter to zero (no negative)
→ Clear SSR fault Flag
Return
Timer / Counter Intrupt
Entry upon Timer / counter being expired
Turn the radios ON
Take the message buffer and load it to the Voice-Synthesizer word by word.
Turn the radios OFF
Append Time & date (From the Real-time clock), to the message, and dump it to the log memory
or
if tape recorder is used turn it on and dump the message there.
Return

FIG. 6b : Talkback Unit Operation Flow-chart ; Intrupts.



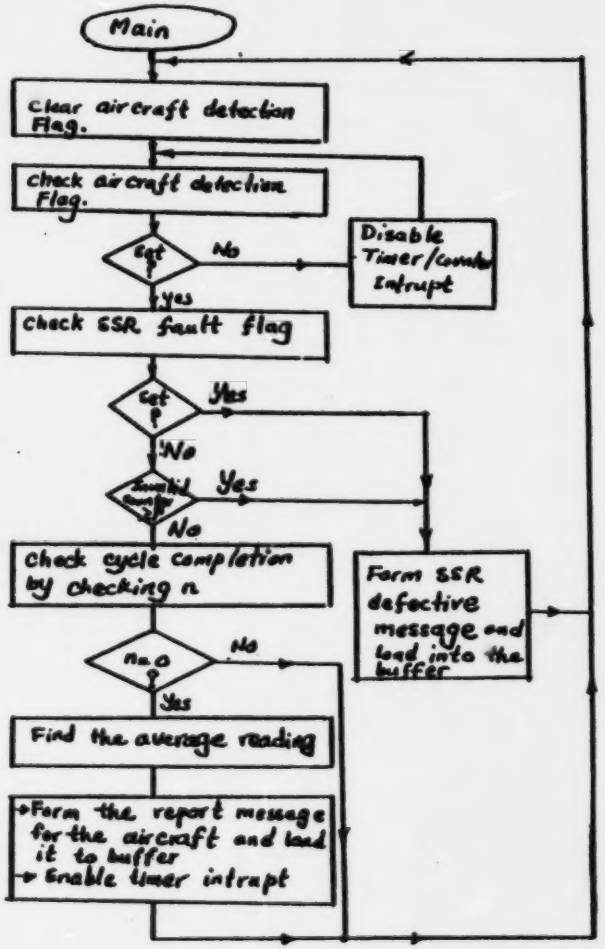


FIG 6C : Talkback Unit operation Flow-Chart; Initialization & backgroun.

Program

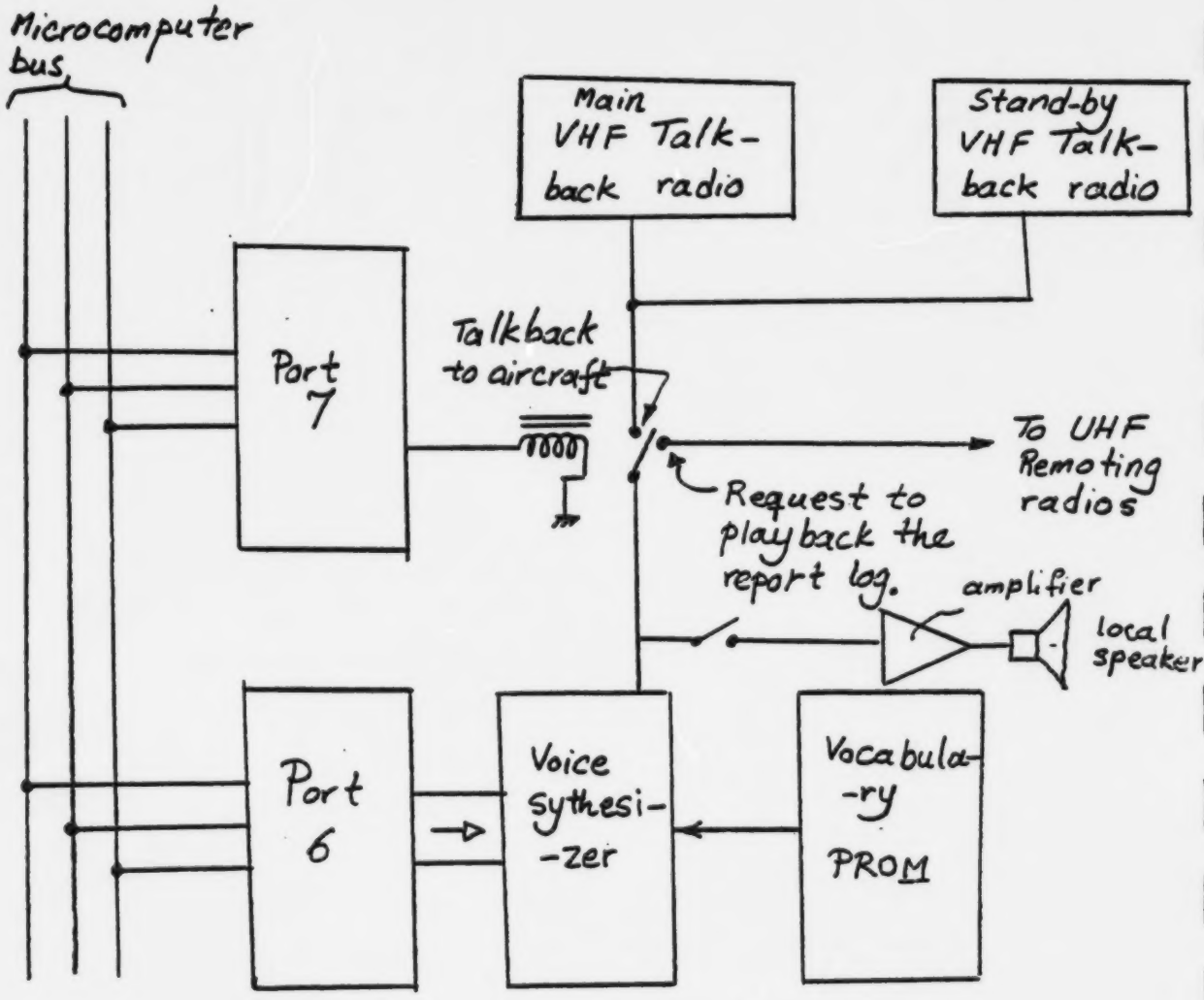


FIG. 6d Play-back of traffic/report log memory through voice synthesizer to UHF remoting radios

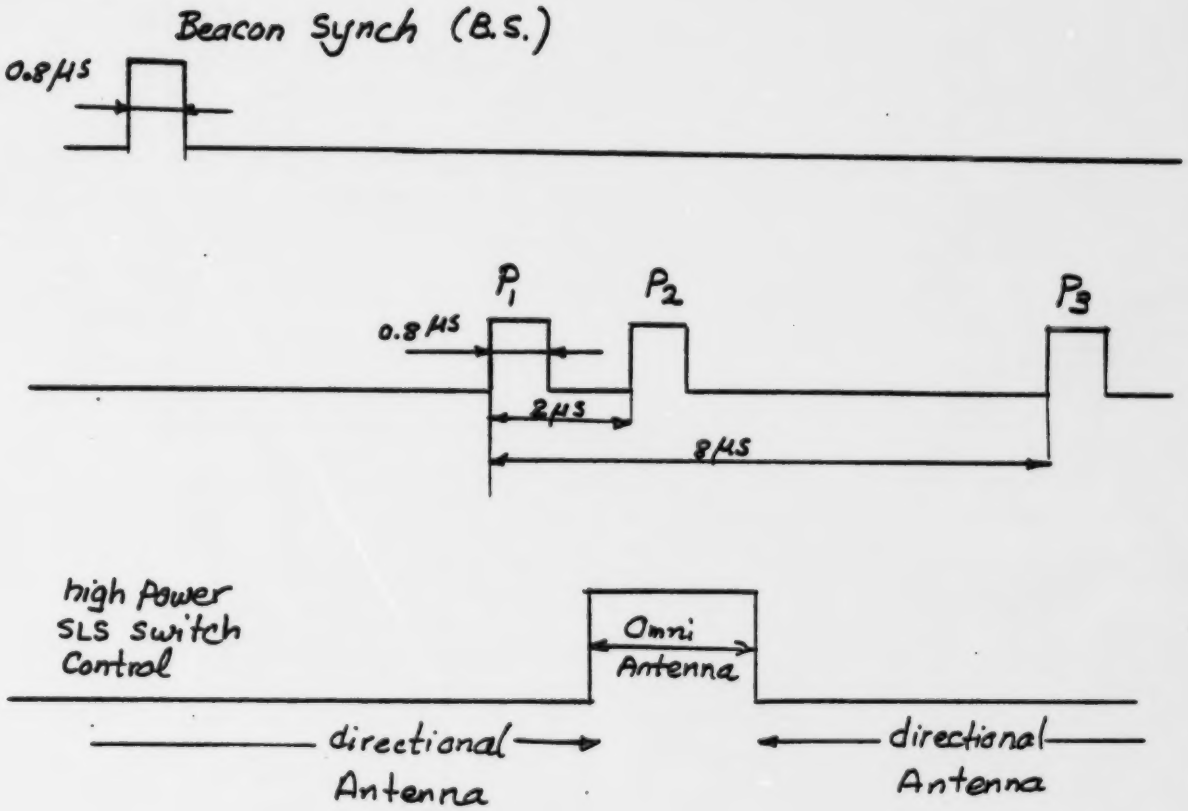


FIG. 7 BASIC SSR PULSES FOR MODE 3A

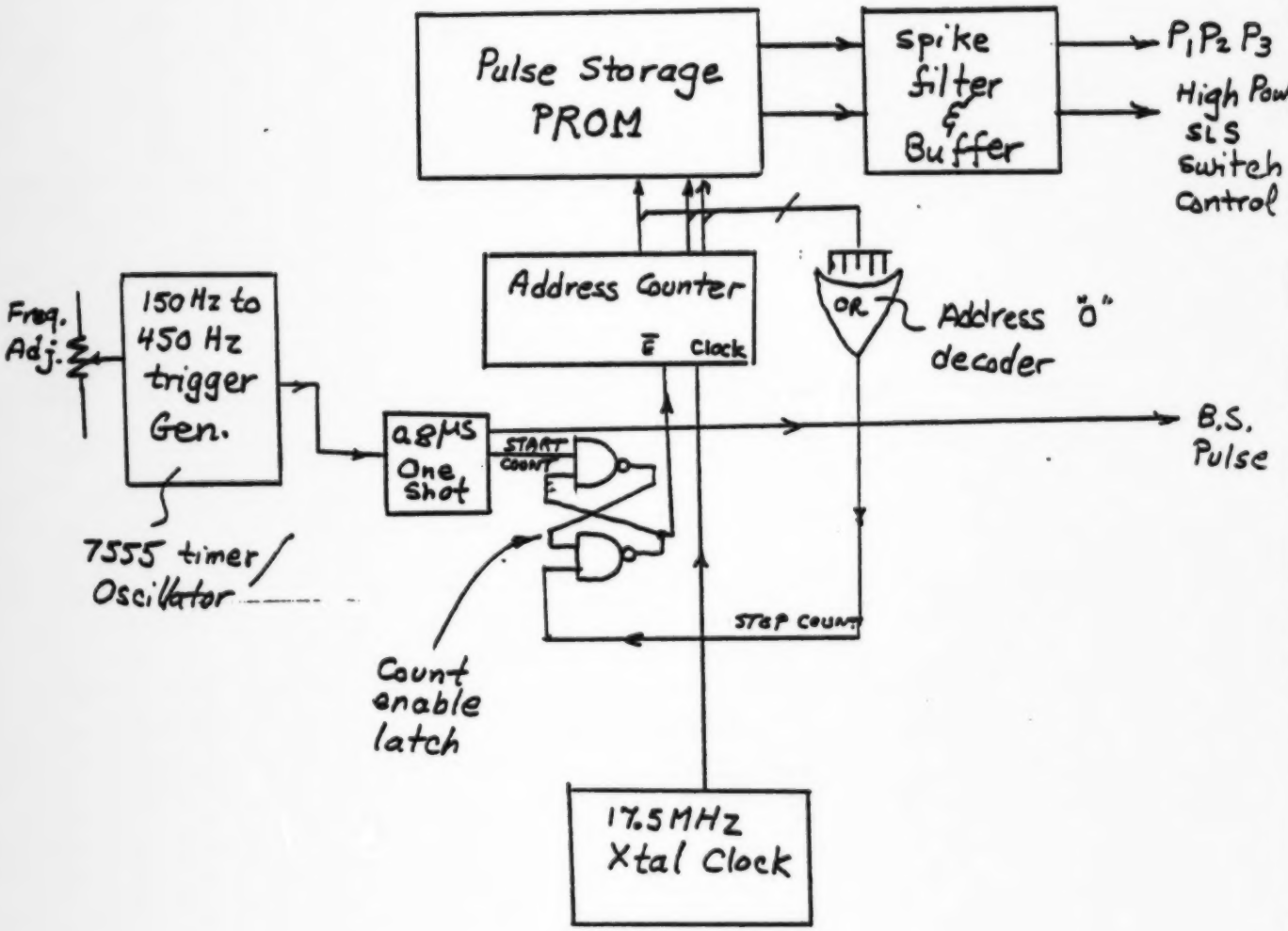


FIG. 8 BLOCK DIGRAM OF THE CODER MODULE

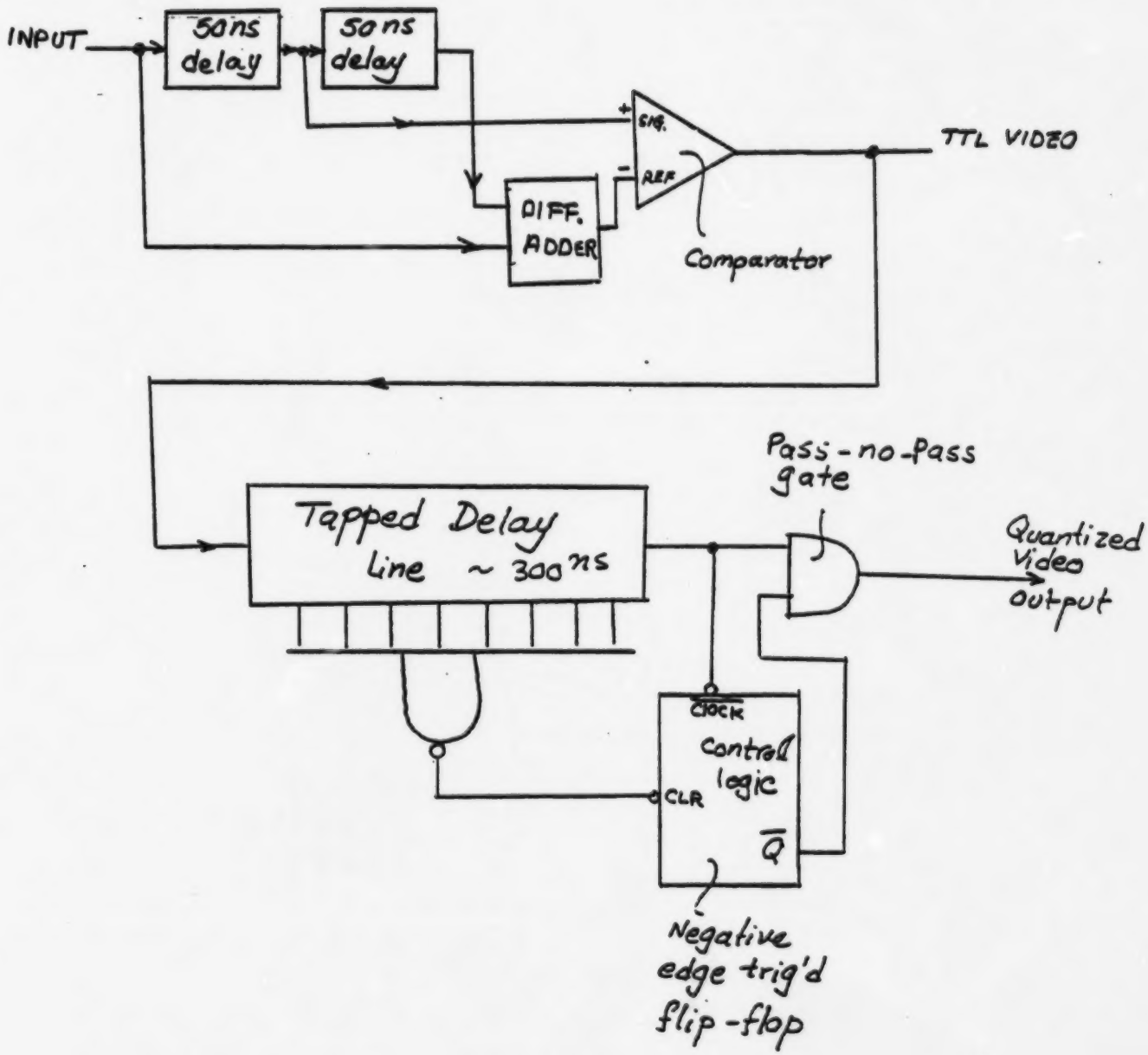


FIG. 9 BLOCK DIGRAM OF VIDEO PROCESSOR

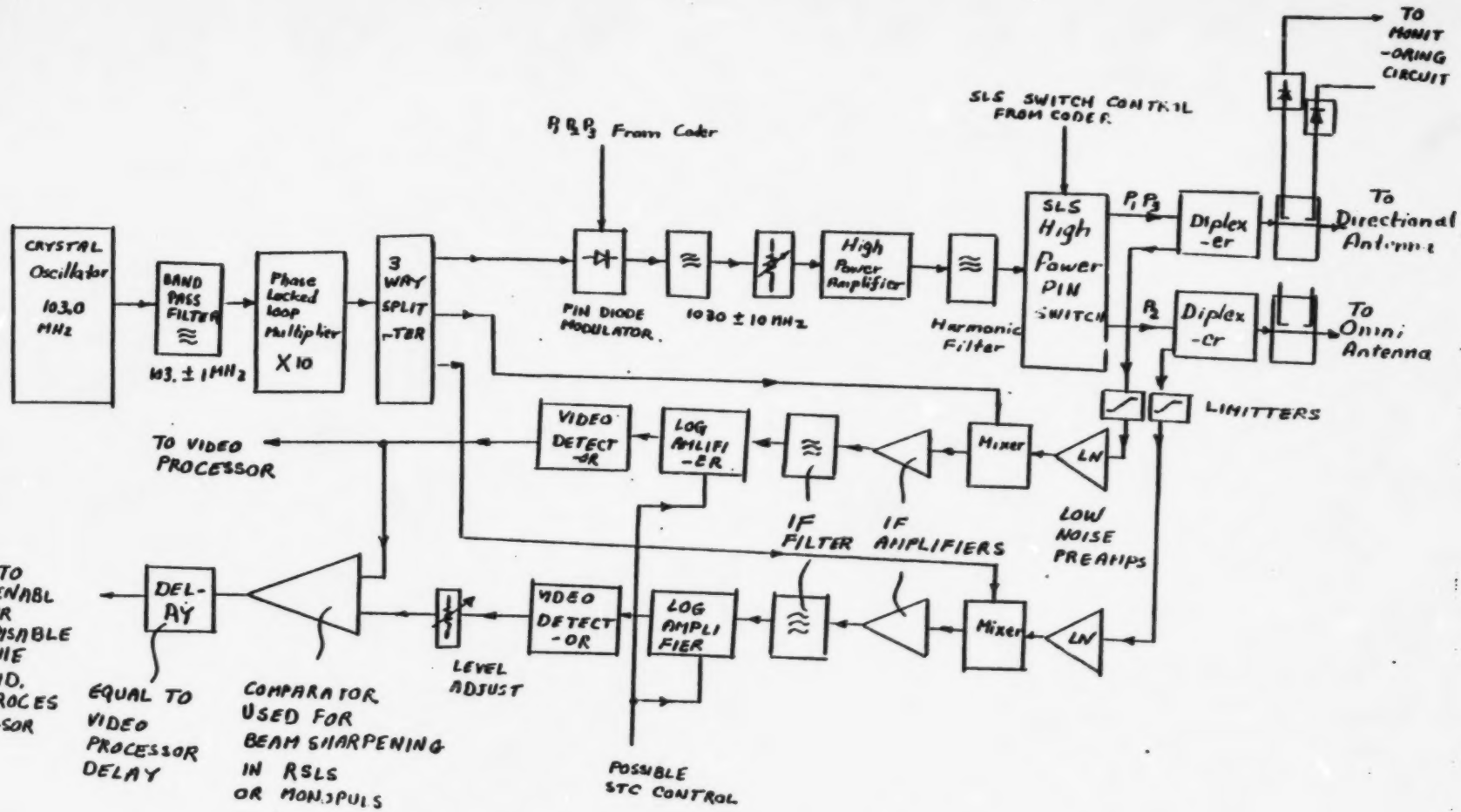


Fig. 10 RF PARTS OF THE PROPOSED SSR

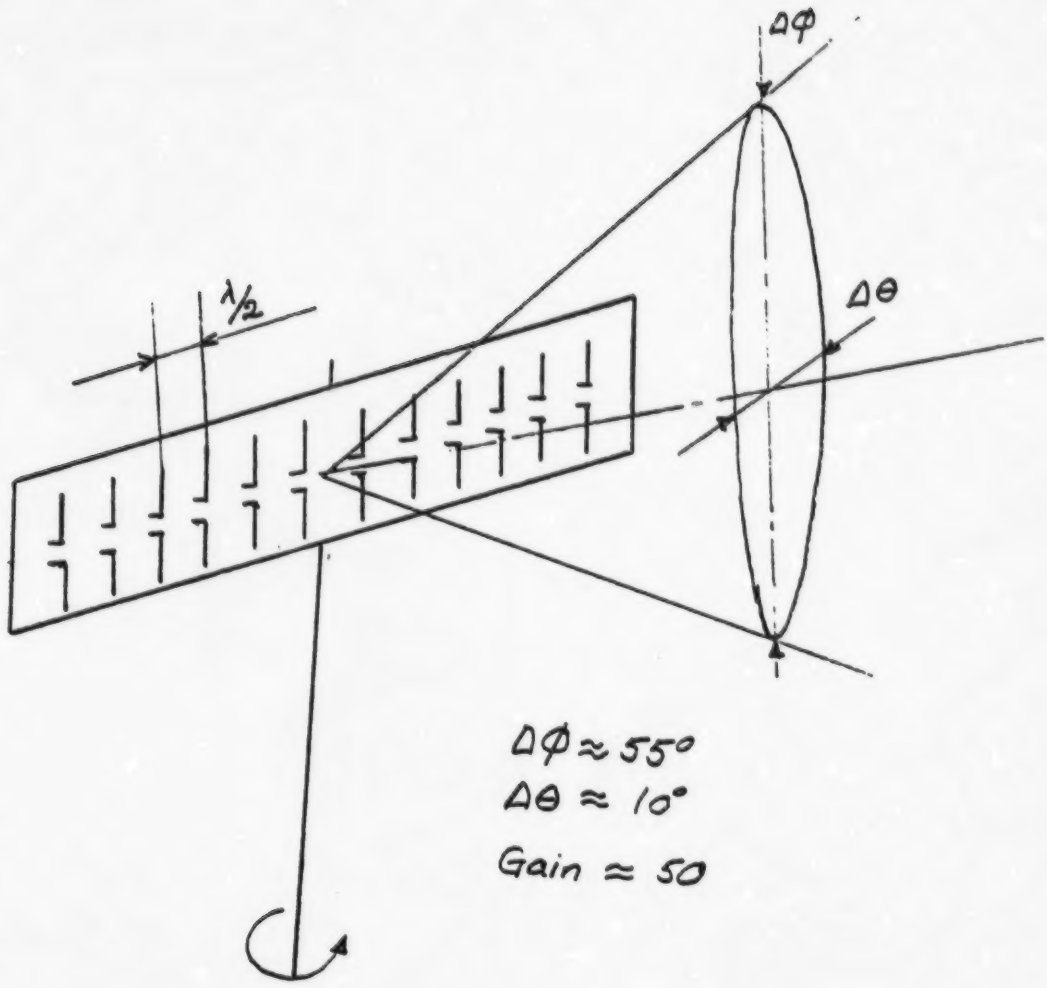


FIG. 11: Design Concept of the Directional Antenna

APPENDIX 1

ATTACHMENT

ON

VLATME TARGET MESSAGE DATA, FORMATS, AND DATA RATES

A. Data Content of Message

B. Message Format

C. Data Communication

A. DATA CONTENT OF MESSAGE

The aircraft message, sent from the Coder and Processor Unit, consists of the following:

a) Range: 12 bits with LSB = 1/16 km

b) Azimuth: 12 bits with LSB = 1 ACP

c) Code #1: 4 digit octal code (with validity bit) for mode 1 or mode 2

d) Code #2: 4 digit octal code (with validity bit) for mode 2 or mode 3

e) Altitude: 3 digit BCD code with barometric correction in hundreds of feet (A = 1 for negative altitude)

f) SPI, Communication Failure (CF), Emergency (Civil or Mil), test target bits.

Number/
Numéro

2

PRELIMINARY DESIGN AND EVALUATION OF A UNAVCOM II FACILITY

SUMMARY REPORT

TP-4696E

REPORT PREPARED BY CANADIAN ASTRONAUTICS LIMITED
UNDER CONTRACT TO THE
TRANSPORTATION DEVELOPMENT CENTRE,
TRANSPORT CANADA

Prepared by: D. Friberg

Reviewed by: W.F. Payne

Released by: D. Friberg

June 1983

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OCT 7 1983
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PROJECT TEAM

The project team for Canadian Astronautics Limited (CAL) was composed of:

Mr. D. Friberg
Mr. D. Vakili
Dr. P. Woods

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of Transport Canada, Transportation Development Centre.

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Summary of "A Preliminary Design and Evaluation of a UNAVCOM II Facility" TP 4570E	Micha Avni

17. Abstract

The intent of the work described here was to develop a preliminary design of a remote navigation and communications designed to improve low and high level services to Canada's remote and arctic airspace. Also included was an evaluation of this system with respect to the technical and financial feasibility of deploying a network of between 35 and 50 such stations.

A general description of the design of the proposed station is included in this report. The anticipated life cycle cost for a ten year period is approximately $700,000 to $1,000,000 and the station will be able to meet all the performance specifications by Transport Canada. The low cost and good performance of this system make it an attractive solution to the present navigation and communication difficulties in these areas.

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	14. Code de l'organisme parrain CDT 4751

15. Remarques additionnelles	16. Agent de projet — CDT
Traduction française d "Preliminary Design and Evaluation of a Unavcom II Facility - Summary Report", TP-4696E	Micha Avni

17. Résumé

Le but du travail décrit dans ce rapport est de développer le projet préliminaire d'une installation pour la navigation et les communications destinée à améliorer les services offerts aux aéronefs naviguant à basse et à haute altitude dans l'espace aérien canadien des régions arctiques, et peu accessible. Le rapport comprend également une évaluation de ce système quant à la faisabilité technique et financière de déployer un réseau de 35 à 50 stations de ce type.

Une description générale du projet de la station proposée est donnée dans le rapport. On prévoit que le coût de la station, pour un durée de vie de dix ans sera d'environs $700,000 à $1,000,000, et qu'elle sera à même de satisfaire à toutes les spécifications fonctionnelles établies par Transports Canada. Le coût modeste et les bonnes charactéristiques fonctionnelles de cet équipement en font une solution séduisante aux difficultés de navigation et de communications qu'on rencontre présentement dans ce régions

18. Mots-clés	19. Diffusion
Installation pour la navigation et les communications sans surveillance	Un nombre limité d'exemplaires est disponsible auprès de l'organisme parrain

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1. INTRODUCTION

This report summarizes the contents of a report entitled, Preliminary Design and Evaluation of a UNAVCOM II Facility (TP4570E). The main report, prepared by Canadian Astronautics Limited, was submitted to the Transportation Development Centre in July 1983. In it, the results of a preliminary design and evaluation study on the feasibility of deploying a remote navigation and communication system in Canada's north are presented. The report deals primarily with the technical problems associated with the design and development of this system.

2. HISTORY

In a study carried out in 1975/76, under contract to the National Airspace Planning Office of Transport Canada, Satel Communications Ltd. identified a requirement for improved low and high level communications and navigation facilities in Canada's remote and arctic areas. The study indicated that these improvements could be implemented by the deployment of remote facilities throughout these areas. It was suggested that these facilities include:

1/ a non-directional beacon
2/ a VHF air/ground communications link
3/ a data and voice communications backhaul link
4/ some means of providing automatic VHF bearing replies

The remoteness of the proposed sites also dictates that the power required to run this equipment be generated on site.

In 1978, the Transportation Development Centre (TDC) of Transport Canada was tasked to undertake the development and evaluation of an Unattended NAVigation and COMmunications (UNAVCOM) facility. During tests conducted between January 1979 and September 1981, encouraging results were obtained except that this first generation UNAVCOM station proved to be very unreliable. It was concluded from this project that a UNAVCOM facility is practical in remote areas but that further development of the prototype would be required.

In November 1982, Canadian Astronautics Limited (CAL) began an evaluation study and preliminary design of a second generation prototype (UNAVCOM II). The results of this work are summarized in this report.

3. OBJECTIVES

The overall objective of the UNAVCOM program is to improve air/ground communication and navigation aids in Canada's remote and arctic airspace. The immediate goal of the work described here is to prepare a preliminary design of a second generation prototype system and to evaluate the capability of this system to provide reliable, cost effective services to Northern Canada. The report also contains recommendations for the development of the UNAVCOM II station from the preliminary design phase through to the delivery to Transport Canada of a fully tested prototype system.

4. SYSTEM SPECIFICATIONS

It is unclear at this time whether every station within the proposed UNAVCOM network will be required to provide all the services discussed in Section 2. In certain areas, particularily those where the supply of fuel to the site may be difficult or expensive, certain functions may be eliminated to lower costs. To make this practical, the UNAVCOM II station will be designed as a series of modules, any or all of which might be included. A system in which all modules are present will be required to:

1/ Provide reliable VHF air/ground voice communications 95% of the time anywhere within a 160 km radius of the site, consistent with line of sight limitations of the local terrain and based on an antenna height of 30 metres above ground level.

2/ Provide a non-directional beacon (NDB) towards which bearings can be obtained accurate to $\pm 5^{\circ}$ for 95% of the readings taken anywhere within a 100 km radius of the site.

3/ Provide automatic bearing and range replies via the VHF air/ground communications link. This information will be obtained using a Talk-back Secondary Surveillance Radar (TSSR).

4/ Provide both voice and data communications between the remote station and a central manned control station. This backhaul system will be linked both to the VHF air/ground system and to a Telemetry and Command System in the UNAVCOM station.

5/ Operate from a stand-alone power source with no connection to the regular electric power grid.

6/ Operate in the field under Arctic conditions for a period of one year without routine maintenance and with a probability of 0.9, or greater, that there will be no total failure of either the navigation or communications subsystems during the year.

7/ Provide an operating availability of 99.9% throughout the year for both NDB bearings and the VHF bearing replies.

5. DESIGN DESCRIPTION

To meet the system specifications outlined in Section 4 the following seven subsystems must be incorporated into the UNAVCOM II station:

ITEM	DESCRIPTION/MODEL NO.	MANUFACTURER
1) Equipment Enclosure	4 metre DND approved aluminum trailer	Champion Truck Bodies
2a) NDB	ND 500	Nautel
2b) NDB Tower	Polestar PA-90-B	Nautel
3) VHF Air/Ground	Johnson 2 way radio model 242-406	Johnson
4) Communications Backhaul	Radio telephone with automatic channel evaluation (RACE)	Canadian Marconi Corp.
5) TSSR	Simplified version developed by CAL. (If available in time)	CAL
6) Power Source	Hybrid Wind/Ormat Turbine proposed for final version, UNAVCOM II testing will be done using regular power grid	Ormat Systems/ Northwind Power Company
7) Telemetry & Command	Custom built	CAL

Table 1 UNAVCOM Subsystem List

An artist's conception of the layout of a typical UNAVCOM site is shown in Figure 1.

The following is a brief description of each of these items:

5.1 Equipment Enclosure

All the electronics equipment in the proposed UNAVCOM II station will be housed in a 4-metre, insulated, aluminum container similar to those used by the Canadian military. These containers are designed to be transportable by helicopter, fixed wing aircraft, rail or truck, the intent being to allow the UNVACOM station to be transported as a single, fully integrated and fully tested system. Figure 2 is an artist's conception of the proposed equipment enclosure.

In addition to providing protection for the electronics equipment, these containers are also large enough to provide emergency shelter for repair and maintenance personnel and will be suitably equipped for this purpose. The inside temperature of the container will be regulated using the waste heat generated by the electronics. The enclosure will be divided into two areas, one in which the electronics will be mounted, which will be heavily insulated, and the other area which will provide emergency shelter will be very lightly insulated. Thermostatically controlled fans will be used to exhaust hot air from the electronics area to the shelter area when it is necessary to increase the rate of heat loss from the container. No regulated vents will be required to vent air directly out of the container.

5.2 Non-directional Beacon

The non-directional beacon (NDB) selected for use in the UNAVCOM II station is similar to those found throughout southern Canada. The pilot will be able to use these beacons in exactly the same manner except that the UNAVCOM stations will be located further apart and it is unlikely that it will be possible for the pilot to calculate his exact position by triangulating three stations.

5.3 TSSR

The TSSR proposed for use in the UNAVCOM II station will be specifically designed for this application. SSR's currently in place at airports in southern Canada are equipped with a number of functions that will not be required in the UNAVCOM network. These functions include altitude determination, military IFF (identification friend or foe) capabilities, and high traffic density capabilities. The simplified SSR will calculate only bearing and range and transmit this information via the VHF radio to the pilot.

5.4 VHF Air/Ground Communications and Communication Backhaul Links

As well as navigation aids, the UNAVCOM station will provide the pilot with a means of communicating with a central air traffic controller. A standard VHF radio will provide a voice communication link from the remote station to the aircraft. These signals will also be transmitted to the central station along with station monitoring information via the communications backhaul link.

In the UNAVCOM II prototype this backhaul will be provided by a MARCONI Radio Telephone with Automatic Channel Evaluation. The system has not been thoroughly tested and due to the inherent uncertainties of HF radio transmission some question exists as to its suitability. The system is however much cheaper than its competitors and therefore it deserves attention in this development program. Should it prove unacceptable, a standard 4/6 GHz earth station may be used in its place or, if it is available in time, the MSAT mobile communication system currently under development by Dept. of Communications (DOC) offers advantages over both. The final decision will be made at the time of deployment.

5.5 Telemetry and Command

A Telemetry and Command system will be provided to allow maintenance personnel to remotely monitor the UNAVCOM station in order to detect system malfunctions and to control the operational status of each of the other subsystems. Data transfer to a computer at the central station will be done via the communications system. The primary intent of the Telemetry and Command system will be to reduce the frequency of maintenance and repair visits. The way in which this can best be accomplished is as yet unclear so the system will be designed to allow modifications on the recommendation of maintenance personnel.

5.6 Power Source

The total power demand for the UNAVCOM station is expected to be approximately 750 watts. The tests performed on the UNAVCOM II prototype will be conducted at a location where regular grid power is available, so no independent power source will be required. However the proposed sites for the actual UNAVCOM network are far too remote to avoid the necessity of generating power on site.

At the present time the Ormat closed cycle vapour turbine appears to be the best means available to generate this power. It is one of the very few power systems able to meet the the reliability requirements of the UNAVCOM system and of those which can, it has the highest efficiency. However, the efficiency is still only 5% and the capital cost is nearly $175,000 CAN.

One of the main reasons for the delay in the purchase of a power source is the hope that better systems will be come available before the end of the UNAVCOM field trial. If not, the ORMAT system will be used, possibly in conjunction with either a wind turbine or photo voltaic array. Both of these alternative energy sources were investigated thoroughly and it has been concluded that significant cost savings are possible using one system or the other at most proposed UNAVCOM sites.

6. SYSTEM RELIABILITY

It is expected that meeting the UNAVCOM reliability specification of 90% probability of one year's successful operation will present some difficulty. Analysis shows that each of the major subsystems will require a fully redundant back-up and even with this back-up, repairs to any failure of a main unit should be made within one month. This will leave the probability of failure of both the prime unit and its back-up occurring at the same time, resulting in a loss of system capabilities at .95 over one year.

The reliability requirement can therefore be met. However a failure to a main unit can be expected every six months on average. If these are repaired promptly, two or perhaps three visits per year per site will be required. The original UNAVCOM II specification is for one visit per year. If repairs can only be made during the scheduled visit per year, the system reliability is estimated at .75. Thus either but not both of these specifications can be met.

7. DEVELOPMENT PLAN

Now that the preliminary design of the UNAVCOM II prototype station has been completed it will be necessary to determine a development plan aimed at advancing the UNAVCOM program from its current conceptual stage to the delivery to Transport Canada of a complete, fully tested UNAVCOM station. Transport Canada has requested that the testing of this prototype include a one-year field trial under actual operating conditions.

The development will therefore consist of two main stages. First the station will be designed and built by Canadian Astronautics Ltd., then subjected to a series of controlled tests in the Ottawa area. The station will then be shipped to a site to be chosen by Transport Canada, and operated for a period of one year. Due mainly to the desire to delay the selection of a power source pending the results of current development work in this area, the field trial will be conducted using the regular hydro grid as a source of power. Concurrently with these field trials, separate tests will be conducted on the selected power source so that it can be integrated into the UNAVCOM facility at the time of the final delivery.

8. COST ESTIMATES

Canadian Astronautics has agreed to undertake the development the development of the UNAVCOM facility, without a power source for $500,000. The cost of the power source development and testing will depend on which system is selected, but will likely cost in the order of $250,000 to $500,000.

With this development complete, the cost breakdown of a single UNAVCOM station is as follows:

SUBSYSTEM NAME	COST	
ENCLOSURE	$ 35,000	
NDB	47,500	
VHF A/G COMMUNICATIONS	10,000	
MARCONI RACE HF TELEPHONE	35,000	
TELEMETRY AND COMMAND	20,000	
TSSR	100,000	
POWER SOURCE	~175,000	- ESTIMATE ONLY
TOTAL	$ 422,500	

Assuming diesel fuel costs roughly $2.50 per litre and the cost per visit to the site is $3,000, the total life cycle cost for a 10-year life is approximately $1,000,000 per site. The figure includes $450,000.00 in fuel costs based on the assumption that an ORMAT Turbine without a wind power or solar power economizer is used. If one of these is used, the total life cycle cost will drop to as low as $640,000 per site.

In order to provide complete coverage in Canada's north, 34 remote stations will be required. An additional 16 stations designed to operate in conjunction with existing facilities will be required if the UNAVCOM system is used in all areas including those with limited navigation and communications facilities already available. The total yearly cost of an entire system would therefore be just under 4 million dollars. This figure is high, but one should bear in mind that this is the cost of complete coverage. Limited coverage, which would also represent an improvement over existing conditions, could be provided using fewer stations. The quality of this service of course would be directly proportional to the number of stations and to the cost. It seems prudent to delay the final recommendation as to the number of proposed sites pending the outcome of the UNAVCOM II field trials.

9. SCHEDULE

The design and construction of the UNAVCOM II prototype station began in June 1983 and is scheduled for completion in June 1984. The one year field trial should therefore be completed in July or August 1985, allowing time to review results. Should a decision be made at this time to proceed with the deployment of a complete UNAVCOM network, at least one year will be required to complete this task, possibly longer depending on the delivery times required for various components. A reasonable estimate of the earliest possible completion date for a complete UNAVCOM network is the summer of 1987. Care should therefore be taken to ensure that full advantage can be taken of all technology available at that time.

10. CONCLUSIONS AND RECOMMENDATIONS

The following is a point by point evaluation of the proposed UNAVCOM II station's ability to meet the specifications as laid down by Transport Canada.

1/ The system is required to provide reliable VHF air ground communications 95% of the time anywhere within a 160 km radius of the site. For the system to do this both a VHF link from the pilot to the remote station and an HF link from the remote station to a central manned station must be established. The VHF equipment in the UNAVCOM II station will be mounted on the NDB tower and no problem is anticipated with this equipment. The MARCONI RACE HF link however has not yet been thoroughly tested, and has been recommended for use in this system primarily due to its low cost. Our major concern with this system is its availability especially during ionic storms. Careful evaluation of this system during the field trial will be required before recommending its use in the operational UNAVCOM network.

2/ The system is required to supply NDB signals towards which bearings can be obtained accurate to ±5° for 95% of the readings taken anywhere within a 100 km radius. This objective was achieved in the UNAVCOM I station and the equipment proposed for the UNAVCOM II station are upgraded versions of the UNAVCOM I equipment.

3/ The station will be required to operate from an internal power source, with no connection to the regular electric power grid. The ORMAT CCVT, with wind or solar economizer, will allow the system to do this. However, in order to allow further development time, no power source will be provided with the UNAVCOM II prototype.

4/ The station must operate in the field under Arctic conditions for a period of one year without routine maintenance and with a probability of .9 or greater that there will be no total failure of either the navigation or communications sub-systems during the year. The reliability of certain system components in particular the RACE system cannot be verified. However indications are that this reliability

figure of .9 is well within the capability of the system providing each subsystem has a redundant unit and repairs to a first failure can be effected within one month. This reliability is not greatly affected by routine maintenance but initial calculations indicate that unscheduled visits to repair damaged but still functional units, will be required every six months on average.

5/ The system must also provide 99.9% availability throughout the year for both NDB bearings and the VHF bearing replies. If the system can be repaired within 30 days, the low scheduled maintenance requirements of the NDB system will allow the NDB to provide 99.9% availability provided the MTBF is 20,000 hrs. as the manufacturer claims. The MTBF of the TSSR however is not yet known. It is reasonable to expect it to match the NDB figures, however we cannot verify this yet.

The anticipated 10 year life cycle cost for a single UNAVCOM station is expected to range between $700,000 and $1,100,000 (1983 CAN) depending on the availability of wind or solar energy. These costs are high, but would be considerably reduced if the basic UNAVCOM specifications were altered.

The following changes have been included as suggestions for review by Transport Canada:

1/ The reliability objective of 0.9, has placed restrictions on the selection of the power supply and forced redundancy on nearly all subsystems. If the reliability objective were reduced to say 0.75, many of these restrictions would disappear. For example, the main reason for rejecting the Mechron cycle charge diesel system was its questionable reliability. If the reliability were relaxed, this system could be used and considerable savings would be realized. This is quite reasonable if UNAVCOM station is considered in its context as a component of a network of stations. A single station failure will not result in the total loss of services, if it is correctly reported and pilots in the area are warned and, if possible, rerouted.

2/ If the operational availability requirement of the navigation aids is lowered, a mode of operation could be envisioned where a base load of the 200 watts required by the communications system would be produced by a highly reliable prime power source while the remaining power would be produced by a soft energy source on a partial availability basis. A 200 W TEG coupled with either a wind generator or photovoltaic system could then be used to produce the required power at a significantly lower price. The inconvenience to pilots could be reduced by allowing VHF requests to turn on the NDB or TSSR as required.

In areas of marginal wind and sunlight, a power supply using a cycle-charge diesel with a propane TEG back-up could also be used to reduce cost.

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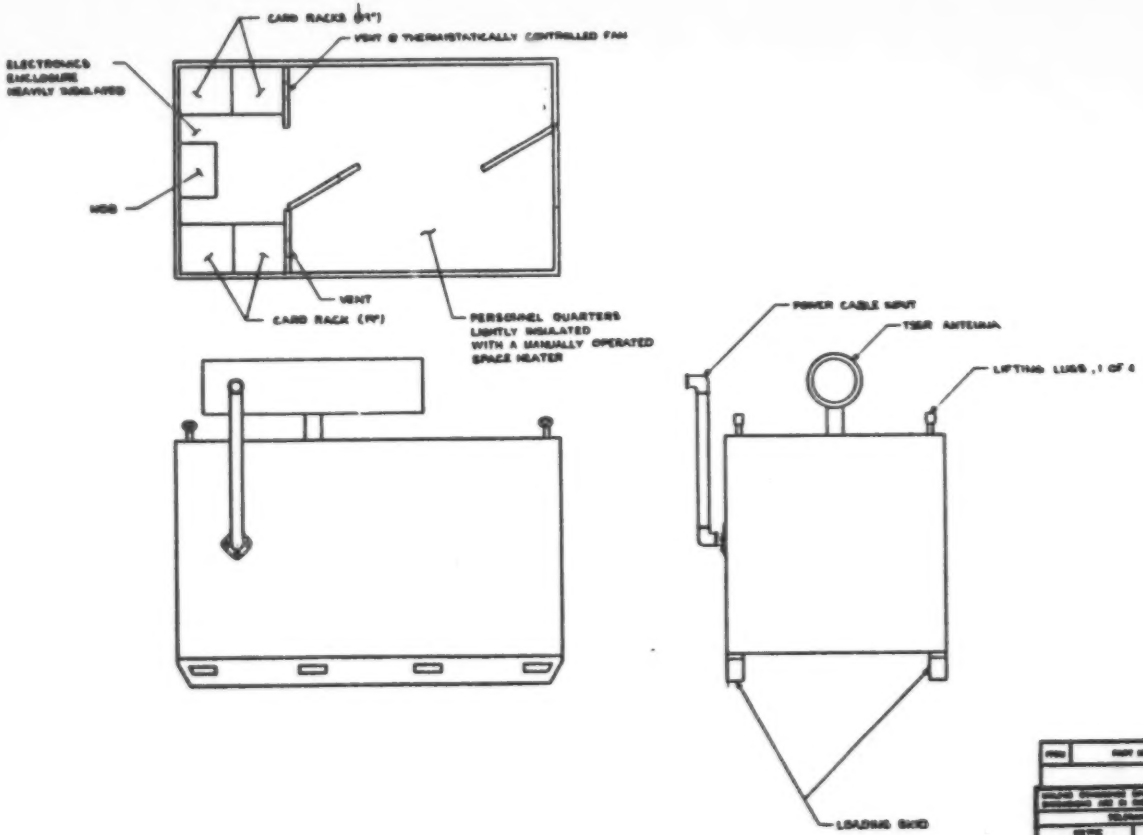

FIGURE 2: UNAVCOM II ELECTRONICS ENCLOSURE

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UNAVCOM II ELECTRONICS ENCLOSURE

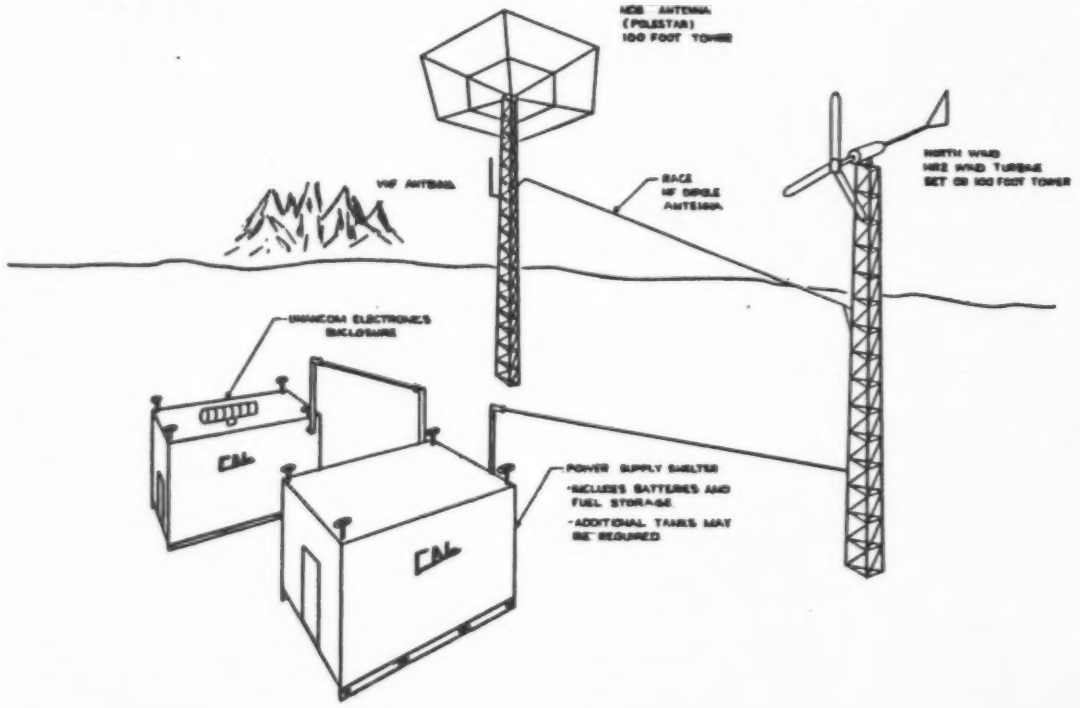

FIGURE 1: POSSIBLE LAYOUT FOR A UNAVCOM STATION EQUIPED WITH WIND TURBINE AND PARTIAL TEG BACK-UP

POOR

QUALITY

ORIGINAL